APPENDIX AVAILABLE ON REQUEST

Communication 15

Proceedings of an HEI Workshop on Further Research to Assess the Health Impacts of Actions Taken to Improve Air Quality

Health Effects Institute

Appendix D. Overview of Published Accountability Studies

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Although this document was produced with partial funding by the United States Environmental Protection Agency under Assistance Award CR–83234701 to the Health Effects Institute, it has not been subjected to the Agency's peer and administrative review and therefore may not necessarily reflect the views of the Agency, and no official endorsement by it should be inferred. The contents of this document also have not been reviewed by private party institutions, including those that support the Health Effects Institute; therefore, it may not reflect the views or policies of these parties, and no endorsement by them should be inferred.

This document did not undergo the HEI scientific editing and production process.

Appendix Table D.1 Overview of Published Accountability Studies [a,b]

Citation	Intervention and Location	Study Design and Period Studied	Air Quality Outcomes	Health Outcomes	Notes
Shorter-term Interventions					
Anto et al. 1993	Restriction of allergen-containing dust. Bag filters were installed in December 1987 on the top of a storage silo in the harbor located near the center of Barcelona, Spain.	Panel study. 38 patients seen during last asthma epidemic before intervention; 148 patients seen after intervention. Period: 9 months before to 24 months after intervention.	Geometric mean concentration of soybean allergens decreased from 324 U/m^3 to 25 U/m^3 on days soybeans were being unloaded. There were no significant differences on days when soybeans were not unloaded (~19 U/m^3).	The number of days with an unusually large number of emergency room visits for asthma decreased from 29 to 6. The rate of admissions to intensive care units for asthma on days soybeans were unloaded decreased from 26 per 100 days to 1 per 100 days. The number of patients who had measurable concentrations of IgE antibodies against soybean allergens decreased slightly from 32 (84%) to 29 (76%).	The authors state that patients with asthma whose symptoms were exacerbated during outbreaks had IgE antibodies that related strongly with glycoproteins from soybean extracts. Serum IgE antibodies against soybean allergens persisted for 2 yr.
Arossa et al. 1987	Reduction of sulfur in oil for heating from 1% to 0.3% by weight in Turin, Italy.	Cross-sectional; longitudinal. 1,880 children who were in the sixth grade in 1980 in central urban and peripheral urban areas of Turin; 162 children of the same age in a suburban area served as a control group. Period: winters of 1980 and 1981 (pre-intervention), and 1982 and 1983 (post-intervention).	Annual mean SO_2 concentration decreased from 200 to 115 µg/m^3 in central Turin, from 155 to 95 µg/m^3 in peripheral Turin, and from 70 to 55 µg/m^3 in suburban Turin. TSP decreased from 150 to 105 µg/m^3 in central Turin, from 135 to 100 µg/m^3 in peripheral Turin, and from 105 to 80 µg/m^3 in suburban Turin.	Before the intervention, there were significant differences in $FEV_{1.0}$, FEF_{25-75}, and MEF_{50} (but not FVC) between children living in suburban Turin and children living in urban Turin (both central and peripheral). After the intervention no significant differences existed in those measures.	
Clancy et al. 2002	Effective September 1, 1990, a ban on sale, distribution, and marketing of bituminous coal within	Time-series. General population, age stratified. Entire population of Dublin (478,389 according to census).	Black smoke decreased from 50 µg/m^3 to 14.6 µg/m^3, annual average (from 85.4 µg/m^3 to 21.5 µg/m^3 during winter).	Nontrauma mortality rates decreased from 9.41 to 8.65 per 1000 person-years (from 11.03 to 9.88 ptpy during winter). Cardiopulmonary mortality	Results were adjusted for concurrent long-term declines in mortality rates.

Citation	Intervention and Location	Study Design and Period Studied	Air Quality Outcomes	Health Outcomes	Notes
	Dublin, Ireland.	Period: 72 months before to 72 months after intervention.	SO_2 decreased from 33.4 μg/m^3 to 22.1 μg/m^3 annual average (from 40.4 μg/m^3 to 24.9 μg/m^3 during winter).	decreased from 4.37 to 3.78 ptpy (from 5.18 to 4.47 ptpy during winter). Respiratory mortality decreased from 1.38 to 1.16 ptpy (from 2.00 to 1.55 ptpy during winter). Other nontrauma mortality rates increased from 3.66 to 3.71 ptpy (from 3.86 to 3.87 ptpy during winter).	
Guo et al. 2008	Sulfur restriction. Area-wide total emission control system introduced in 1972 to control sulfur emissions in Yokkaichi, Japan.	1,232 patients registered in Yokkaichi City between 1973 and 1988. Control group: the entire population of Mie Prefecture (about 1.5 million total; about 220,000 in Yokkaichi). Age-stratified. Period: 3 to 28 yr after intervention (1975–2000).	SO_x concentrations decreased from as much as 1 ppm to less than 0.01 ppm.	All-cause mortality remained significantly higher in patients from Yokkaichi compared with the general population; COPD mortality was almost 10 to 20 times higher, and asthma mortality was more than 20 times higher. Mortality rates for other causes were not significantly different. With the exception of males 80–84 years old (in 1985), all ages showed significantly lower life-expectancy in Yokkaichi than in the general population.	The authors state that the incidence of COPD and bronchial asthma began to rise in the early 1960s in the population of Yokkaichi. It was thought to be associated with sulfur emissions, leading to the restrictions. There are a number of other risk factors for COPD, such as cigarette smoking, that were not taken into account.
Hedley et al. 2002	SO_2 in fuel restricted to 0.5% by weight in Hong Kong, effective July 1, 1990.	Time-series. General population of Hong Kong, age-stratified. Period: 5 yr before to 5 yr after 1990 intervention.	Mean SO_2 decreased from 44.2 μg/m^3 pre-intervention to 20.8 μg/m^3 1 yr after intervention but increased to 24.5 μg/m^3 5 yr after intervention. Other pollutants (SO_4 in PM_{10}, NO_2, O_3) were reduced slightly after 1 yr but went back to pre-intervention levels after 5 yr. PM_{10} remained unchanged.	The relative change in annual trends in mortality were decreases of 2.11% for all-cause mortality, of 3.94% for respiratory mortality, and of 2.01% for cardiovascular mortality. These relative changes corresponded with a decrease of 1.08% per 10-μg/m^3 decrease in SO_2 for all causes, –2.02% for respiratory, and –1.03% for cardiovascular mortality. All-cause and cardiovascular effects were larger for those aged 65 yr and older than for those aged 15–64 yr, but respiratory effects were larger for those aged 15–64 yr.	The study was unable to separate effects from the reduction in SO_2 from the effects of reductions in other combustion products that may have been unrelated to the introduction of low-sulfur fuels.

Citation	Intervention and Location	Study Design and Period Studied	Air Quality Outcomes	Health Outcomes	Notes
Hugosson et al. 2006	Congestion charging to enter the inner city of Stockholm, Sweden. Trial from January 3, 2006, to July 31, 2006.	Modeling. General population of Greater Stockholm. Period: during the 7-month intervention.	Average (citywide) NO_x was calculated to have decreased by 5–10 µg/m^3; PM_{10} by 2–3 µg/m^3. Projected changes differed among roads and were projected to increase on some road sections just outside the zone.	Estimate of 5 life-years per year saved in Greater Stockholm. The authors report other calculations that estimated up to 25–30 premature deaths prevented per year, corresponding to about 300 life-years.	The intervention included increased public transportation and creation of locations where people park and take public transportation. The authors state that predicted traffic decrease was 15–20%; actual decrease was 22%. There was an increase in traffic on some roads outside the congestion charging zone.
Imai et al. 1986	Sulfur restriction. Area-wide total emission control system introduced in 1972 to control sulfur emissions in Yokkaichi, Japan.	Longitudinal. General population, age-stratified by polluted area (SO_x > 1.5 mg/100 cm^2 X day) vs. control area (at least 5 km from factories, with SO_2 concentrations that had never exceeded national ambient air quality standards). Period: 9 yr before to 11 yr after intervention (1963-1982, subdivided into 5 periods).	SO_x in polluted areas increased from 0.9 mg/day in 1964 to more than 2.0 mg/day in 1970. After the intervention, SO_x decreased to 0.3 mg/day in 1982 with > half the decline occurring between 1971 and 1973. NO_2, TSP, and photo oxidant concentrations remained almost constant between 1974 and 1982 and are thought to have been similar in earlier years as well.	Mortality due to bronchial asthma and chronic bronchitis in the polluted area declined from 4.36 to 0.33 per 100,000 person-years, which was similar to mortality of 0.44 per 100,000 person-years observed over 20 yr in the control area (including pre- and post-intervention periods). The rank correlation coefficients between SO_x levels and mortality due to chronic bronchitis had the highest significance when the lag was set to 4 or 5 yr.	
Martins et al. 2001	Wintertime vehicle restriction from 1996–1998 in the São Paulo, Brazil, metropolitan region.	Time-series. Population 65 yr and older in São Paulo. Period: 1 winter with partial restriction (1996) and 2 winters with total (year round) restriction (1997 and 1998).	Mean O_3 decreased from 69.3 mg/m^3 in the first period to 55.9 and 66.9 mg/m^3 in the second and third periods, respectively. Other pollutants were also reduced: CO, 4.5 – 4.7 – 3.7 ppm; NO_2 , 141.1 – 144.9 – 110.2 mg/m^3; SO_2, 22.6 – 18.7 – 16.9 mg/m^3; PM_{10}, 73.5 –77.3 – 59.8 mg/m^3. (Values represent 1996 – 1997 – 1998.)	CO and SO_2 were significantly correlated with emergency room visits by elderly patients for upper respiratory infections. No reduction in emergency room visits for upper respiratory infections was detected after vehicle restrictions.	Pollutants were correlated, making it difficult to detect effects of single air pollutants. There were no pre-intervention pollutant measurements.

Citation	Intervention and Location	Study Design and Period Studied	Air Quality Outcomes	Health Outcomes	Notes
McCracken et al. 2007	Cook stove improvement in 18 villages near San Lorenzo and Comitancillo in San Marcos, Guatemala.	Randomized trial. 49 women > 38 yr in chimney stove trial group, 71 women in open wood fire control group. Case-control: original control group received chimney stoves at the end of the trial period ("echo" intervention). 55 women were followed before and after the intervention. Period: July 2003–December 2005.	Trial period: Daily average personal $PM_{2.5}$ exposures were 264 and 102 $\mu g/m^3$ in the control and intervention groups, respectively. Echo intervention: Personal $PM_{2.5}$ exposure decreased ~38% after the echo intervention.	Trial group was tested on average 293 days after the intervention. Adjusted mean systolic BP was 3.7 mm Hg lower ($P = 0.10$), and diastolic BP was 3.0 mm Hg lower in the trial group ($P = 0.02$) compared with the control group. Echo-intervention group was tested before and on average 63 days after the intervention. Systolic BP was decreased by 3.1 mm Hg ($P = 0.01$) and diastolic BP was decreased by 1.9 mm Hg ($P = 0.01$) compared with BP before the intervention.	Wood smoke was vented outside, which significantly improved indoor air quality. However, venting smoke outside may under some conditions lead to deteriorated ambient air quality. The original trial did not include pre-intervention measurements.
Peters et al. 1996	SO_2 in fuel restricted to 0.5% by weight in Hong Kong, effective July 1, 1990. Two districts: one with good air quality (Southern) and one with poor air quality (Kwai Tsing) before the intervention.	Cross-sectional. 3,521 children with mean age 9.5 yr. Period: 1 yr before to 1 yr after intervention.	After the intervention, SO_2 levels in the polluted district decreased by up to 80%, and SO_4 in PM_{10} by 38%. No such changes were observed in the other district.	Before the intervention, there were significant excess risks for children in Kwai Tsing for any cough or sore throat (OR, 1.22), any wheeze or asthmatic symptoms (OR, 1.27), and wheezing (OR, 1.34). No significant differences were seen between the two districts after the intervention.	Study examined effect of air quality intervention as well as exposure to environmental tobacco smoke. The authors state that the risks to respiratory health for children exposed to tobacco smoke in the home were higher than those for air pollution in 1989 and 1990 and remained unchanged in 1991 (after the intervention).
Strauss 1975	Restriction of allergen-containing dust. Industrial processing of castor beans in Ourinhos, Brazil, was stopped in 1965.	Panel study. 17 individuals allergic to castor beans in Ourinhos, Brazil, aged 5–68. Period: Just before to 4.6 yr after intervention.	No air quality measurements were made.	12 of 17 individuals with castor bean allergy had become symptom free by 4.6 yr after the intervention. Asthma incidence decreased from 17 to 3 individuals. There was a 30% decrease in positive skin tests for castor beans.	
Tonne et al. 2008	Congestion charging to enter the inner city of London, U.K., effective February 2003.	Modeling; longitudinal, cross-sectional. General population between 30 and 90, stratified by age and socioeconomic	Modeled NO_2 concentration decreased from 54.7 to 54.0 $\mu g/m^3$ in CCZ wards (from 39.9 to 39.8 $\mu g/m^3$ in Greater London). Modeled	Decreases in modeled NO_2 were calculated to yield 26 years of life gained per 100,000 during 10 yr in Greater London (183 years of life gained per 100,000 in CCZ wards).	The predicted changes in air quality were very small. There were simultaneous increases in bus routes and taxi trips that may have offset air

Citation	Intervention and Location	Study Design and Period Studied	Air Quality Outcomes	Health Outcomes	Notes
		deprivation. Entire population of Greater London (~7.2 million) with ~370,000 in CCZ wards. Period: projections up to 10 yr post-intervention.	PM_{10} concentration decreased from 30.3 to 30.1 μg/m^3 in CCZ wards (no change at 26.2 μg/m^3 in Greater London). Across Greater London, estimated decreases were larger for those in higher deprivation groups.	There were 60 years of life gained per 100,000 for the highest deprivation group. Decreases in modeled PM_{10} in Greater London were calculated to yield 8 years of life gained per 100,000 during 10 yr (63 years of life gained per 100,000 in CCZ wards). There were 20 years of life gained per 100,000 for the highest deprivation group.	quality benefits from reduced car trips.
Wong et al. 1998	SO_2 in fuel restricted to 0.5% by weight in Hong Kong, effective July 1, 1990. Two districts: one with good air quality (Southern) and one with poor air quality (Kwai Tsing) before the intervention.	Cross-sectional cohort. Non-asthmatic, non-wheezing children in primary school grades 4, 5, and 6 (9–12 yr) were assessed for bronchial (hyper)reactivity using a histamine challenge. Period: pre-intervention to 1 and 2 yr after intervention.	Mean SO_2 concentrations decreased from 124.5 to ~25 μg/m^3 in Kwai Tsing and remained stable at 2–13 μg/m^3 in Southern.	In the polluted district, BHR declined from 29% pre-intervention to 16% 1 yr post-intervention ($P = 0.026$); BR slope declined from 48 pre- to 39 1 yr post-intervention ($P = 0.075$). In the less-polluted district, BHR declined from 21% to 10% ($P = 0.001$), and BR slope declined from 42 to 36 ($P > 0.100$). Smaller changes were observed in the second year after the intervention.	
Longer-term Interventions					
Chay and Greenstone 2003	Air quality improvements due to Clean Air Act 1970. Strict regulations were placed on industrial polluters in "non-attainment" areas.	Cross-sectional; longitudinal; econometric. 12,450,480 infants < 1 yr old (~2 million infants for each year studied) in 501 U.S. counties. Period: 1996–1974.	Average TSP decreased more than 18% between 1971 and 1974.	A 1% decrease in TSP resulted in an ~0.5% decrease in infant mortality rate, with the largest reduction in deaths occurring within 1 month of birth. There was a greater calculated reduction in infant mortality in non-attainment counties. An estimated 1,300 fewer infants died in 1972 than would have died in the absence of the Clean Air Act.	
Dominici et al. 2007	Long-term improvements in air quality in the U.S. between 1987 and	Time-series. Study population of the National Mortality, Morbidity, and Air Pollution Study.	Both PM_{10} and $PM_{2.5}$ annual averages declined between 1987 and 2003. Mean county annual PM_{10}	Results suggested that the 1-day lagged effects of PM_{10} on mortality declined during 1987–2000 and that this decline occurred mostly	

Citation	Intervention and Location	Study Design and Period Studied	Air Quality Outcomes	Health Outcomes	Notes
	2000.	Period: 1987–2000 for PM_{10} estimates (subdivided into two periods: 1987–1994 and 1995–2000); 1999–2000 for $PM_{2.5}$ estimates.	decreased from ~35 μg/m^3 in 1987 to ~25 μg/m^3 in 2003. $PM_{2.5}$ decreased from ~18 μg/m^3 in 1987 to ~11 μg/m^3 in 2003.	in the eastern U.S. The percentage increase in all-cause mortality associated with a 10-μg/m^3 increase in PM_{10} at lag 1 was 0.21 for 1987–1994 and 0.18 for 1995–2000. Cardiorespiratory deaths: 0.28 for 1987–1994 and 0.21 for 1995–2000. Other-cause mortality: 0.15 for 1987–1994 and 0.17 for 1995–2000. $PM_{2.5}$ had similar associations with mortality, although there was more uncertainty in the estimates.	
Jerrett et al. 2007	Long-term improvements in air quality in the U.S. between 1982 and 2000.	Prospective cohort (American Cancer Society). 264,299 individuals from 51 U.S. cities. 100,557 in sub-sample for mobility models, age and geographically stratified. Period: 1982–2000 (subdivided into 5 periods).	No direct measurements provided. Estimated exposure to $PM_{2.5}$ and SO_4 is included in the risk calculations.	Relative risks associated with SO_4 exhibited a large decline from the 1980s to the 1990s. In contrast, relative risks associated with $PM_{2.5}$ were larger later in the 1990s. The reduction in SO_4 relative risks may have resulted from air quality improvements that occurred through the 1980s and 1990s in response to the acid rain control program. Relative risks appeared to be larger for lower-education groups. Almost all subgroups had higher relative risks in earlier periods.	The authors state that $PM_{2.5}$ concentrations declined in many places, but that mobile sources are now the largest contributors to PM in urban areas. They hypothesize that this may account for the heightened relative risk of mortality associated with $PM_{2.5}$ in the 1990s.
Laden et al. 2006	Long-term decreases in $PM_{2.5}$ concentrations in the U.S. between 1974 and 1998.	Prospective cohort (Harvard Six Cities study follow-up). 8,096 white adults living in Harriman, TN; Portage, WI; Steubenville, OH; St. Louis, MO; Topeka, KS; and Watertown, MA. Period: 1974–1998 (divided into Period 1:	Annual mean $PM_{2.5}$ concentrations decreased in all cities but most noticeably in the dirtiest cities. $PM_{2.5}$ declined on average 7 μg/m^3 per decade in Steubenville, 5μg/m^3 in St. Louis, 3 μg/m^3 in Watertown, 2 μg/m^3 in Harriman, 1 μg/m^3 in Portage, and less than 1	Reduced $PM_{2.5}$ concentrations were associated with reduced mortality risk. The all-cause mortality rate ratio for each 10-μg/m^3 increase in average annual $PM_{2.5}$ concentration was 1.17 (P = 0.0001) in Period 1 and 1.13 (P = 0.03) in Period 2. When controlled for exposure in Period 1, each 10-μg/m^3 decrease in mean $PM_{2.5}$ in	The authors state that $PM_{2.5}$ monitoring in the six cities was discontinued after Period 1. All values in the second period are estimated concentrations.

Citation	Intervention and Location	Study Design and Period Studied	Air Quality Outcomes	Health Outcomes	Notes
		1974–1989 with 104,243 person-years of follow-up, and Period 2: 1990–1998 with 54,735 person-years of follow-up).	μg/m^3 in Topeka.	Period 2 was associated with a mortality rate ratio of 0.73 (P = 0.019). There were reductions in cardiovascular and respiratory mortality risk in Period 2 compared with Period 1, but little evidence of reductions in lung cancer risk.	
Pope et al. 2009	Long-term improvements in air quality in the U.S. during the 1980s and 1990s.	Prospective cohort. General population of 217 counties in 51 metropolitan areas (83,110,000 in 1980 and 104,594,000 in 2000). Period: 1978–1983 and 1997–2001.	$PM_{2.5}$ concentrations in the 51 metropolitan areas decreased from 20.6 ± 4.4 μg/m^3 in 1979–1983 to 14.1 ± 2.9 μg/m^3 in 1999–2000.	Life expectancy increased from 74.32 ± 1.52 in 1978–1982 to 77.04 ± 1.82 in 1997–2001. A decrease of 10 μg/m^3 in $PM_{2.5}$ was associated with an estimated increase in mean life expectancy of 0.61 yr (P = 0.004). In models controlling for a variety of population characteristics, a decrease of 10 μg/m^3 in $PM_{2.5}$ over time was associated with an increase in life expectancy of 0.55–1.01 yr depending on the adjustments for smoking and socioeconomic and demographic factors (P < 0.05 for all models).	Population-based analysis limited the ability to control for individual and community risk factors that could have been affected by policies related to environmental regulation. Limited monitoring of $PM_{2.5}$ constrained the specificity of evaluations of spatial and temporal associations.
U.S. EPA 1999	Air quality improvements due to Clean Air Act Amendments of 1990. The amendments limited the emissions of chemicals that deplete stratospheric O_3 and required a new permitting system for primary sources of air pollution.	Modeled health impacts. General population stratified by Criteria Air Pollutant Modeling System grid cell. Period: 1990–2010.	The projected emissions reductions for 2000 were 27% for VOCs, 26% for NO_x, 25% for SO_2, 15% for CO, 2% for primary PM_{10}, and 2% for primary $PM_{2.5}$. The projected emissions reductions in 2010 were 35% for VOCs, 39% for NO_x, 31% for SO_2, 23% for CO, 3% for primary PM_{10}, and 4% for primary $PM_{2.5}$.	Projected decreases associated with estimated PM reductions: mortality for ages 20 and older (by 23,000 or 1%) and chronic bronchitis (by 20,000 or 3.14%). Decreases associated with O_3 reductions: chronic asthma (by 7,200 or 3.83%). PM, CO, NO_2, SO_2, and O_3 combined: reductions in respiratory hospital admissions (by 22,000 or 0.62%) and cardio-vascular hospital admissions (by	

Citation	Intervention and Location	Study Design and Period Studied	Air Quality Outcomes	Health Outcomes	Notes
				42,000 or 0.86%). PM and O_3 combined: reductions in emergency room visits for asthma (by 4,800 or 0.55%). A number of minor illnesses were estimated to decrease as well, including a reduction of 10.44% in respiratory illness associated with projected reductions in NO_2.	

[a] This table was provided as background material for the Workshop and includes published studies that assessed exposure and/or health outcomes associated with actions to improve air quality. It was not meant to provide a comprehensive overview of all accountability studies of air pollution and health conducted to date. Criteria for inclusion were (1) the study included an exposure or health outcome assessment; and (2) the study was either of short-term actions and events, both in the U.S. and elsewhere, or of long-term changes in the U.S. Assessments of the following types of events were not included: natural or other unplanned events, such as closures, strikes, or economic recession; and long-term changes in air quality outside the U.S., such as studies in Germany that assessed complex air quality changes due to regulatory, economic, and other societal changes that cannot easily be compared with the U.S.

[b] Abbreviations: BHR = bronchial hyperreactivity; BP = blood pressure; BR = bronchial reactivity; CCZ = congestion charging zone; CO = carbon monoxide; COPD = chronic obstructive pulmonary disease; $FEF_{25\text{-}75}$ = forced expiratory flow between 25 and 75% of FVC; $FEV_{1.0}$ = adjusted forced expiratory volume in 1 second; FVC = forced vital capacity; IgE = immunoglobulin-E; MEF_{50} = maximal expiratory flow at 50% of FVC; NO_2 = nitrogen dioxide; NO_x = nitrogen oxides; ptpy = per thousand person-years; O_3 = ozone; OR = odds ratio; $PM_{2.5}$ = PM less than or equal to 2.5 µm in aerodynamic diameter; PM_{10} = PM less than or equal to 10 µm in aerodynamic diameter; SO_2 = sulfur dioxide; SO_x = sulfur oxides; SO_4 = sulfate; TSP = total suspended PM; VOCs = volatile organic compounds.

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