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A fresh look at the benefits and costs of the US acid rain program

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Abstract

The US Acid Rain Program (Title IV of the 1990 Clean Air Act Amendments) has achieved substantial reductions in emissions of sulfur dioxide (SO_2) and nitrogen oxides (NO_x) from power plants in the United States. We compare new estimates of the benefits and costs of Title IV to those made in 1990. Important changes in our understanding of and ability to quantify the benefits of Title IV have occurred. Benefits to human health now take a much higher profile because the contribution of SO_2 and NO_x emissions to the formation of fine particulate ($PM_{2.5}$) is substantial, and evidence of the harmful human health effects of $PM_{2.5}$ has emerged in the last 15 years. New estimates of the health benefits of $PM_{2.5}$ reductions are the largest category of quantified health and environmental benefits and total over US$100 billion annually for 2010 when the program is expected to be fully implemented. Although important uncertainties exist in any specific estimate of the benefits, even if the estimates were calculated using more limiting assumptions and interpretations of the literature they would still substantially exceed the costs. Estimates of annualized costs for 2010 are about US$3 billion, which is less than half of what was estimated in 1990. Research since 1990 also suggests that environmental problems associated with acid deposition and nitrogen deposition are more challenging to resolve than originally thought and will require larger reductions in emissions to reverse. The greater than expected benefits to human health, the greater vulnerability of natural resources and ecosystems, and the lower than expected costs all point to the conclusion that further reductions in SO_2 and NO_x emissions from power plants beyond those currently required by Title IV are warranted.

Keywords: Acid rain; Air pollution; Cost-benefit analysis; Program assessment

1. Introduction

Title IV of the 1990 Clean Air Act Amendments (CAAA), also known as the Acid Rain Program, has achieved substantial reductions in US electric power industry emissions of sulfur dioxide (SO_2) and nitrogen oxides (NO_x) at lower costs than originally predicted. New estimates of the human health and environmental benefits of Title IV are calculated and contrasted with the US Environmental Protection Agency's (US EPA's) most recent estimates of the costs of Title IV. The benefits are estimated using the US EPA's most recent projections of emissions of SO_2 and NO_x from power plants in 2010, after Title IV is fully implemented, in comparison to projections of what emissions would have been in 2010 without the Title IV regulations.

Congress passed Title IV of the 1990 CAAA to reduce emissions of SO_2 and NO_x from fossil fuel-fired power plants. The SO_2 program is a departure from previous regulatory approaches because it sets an overall emissions cap and allows trading of emissions allowances between facilities, thereby creating flexibility for the regulated entities to find the lowest cost approach to reducing total emissions. The permanent cap on total annual SO_2 emissions to be reached in 2010 is 8.95 million tons, which is about half the amount emitted by power plants in 1980. The Title IV NO_x provisions are emission rate limits based on available control technologies. NO_x emissions from power plants are also being reduced by Title I, under which the National Ambient Air Quality Standards (NAAQS) are implemented. Since proposals to reduce power plant emissions beyond the Title IV requirements are under consideration by the Administration and by Congress, it is timely to reassess what Title IV has accomplished.

The Acid Precipitation Act of 1980 (PL 96-294, Title VII) established a federal interagency task force that

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instituted the National Acid Precipitation Assessment Program (NAPAP). NAPAP provides information for policy and regulatory decisions on acid deposition, and to this end NAPAP conducted a 10-year scientific, technological, and economic study of the relationships among fossil fuel combustion, acids, and other air pollutants formed by combustion emissions, and the effects of these pollutants on the environment, the economy, and human health. NAPAP (1991) then issued the 1990 Integrated Assessment, which summarized the technical information and its implications regarding the environmental and economic costs and benefits of alternative control options.

NAPAP's assessment work was path breaking, but considerable research and analysis has been done since 1990 and much has changed in how we assess Title IV. Improved air pollution fate and transport modeling tools and new published research on the human health and environmental effects from power plant emissions are now being widely used by federal and state agencies to assess the expected effectiveness of proposed regulations. The focus of the 1990 NAPAP assessment was on SO_2 emissions and resulting acid aerosols and acid deposition. Some consideration of NO_x emissions was included because they contribute to the formation of acid aerosols, acid deposition, and ozone. However, very little attention was given to the effects of nitrogen deposition and fine particulate matter ($PM_{2.5}$, for which SO_2 and NO_x emissions are important precursors). Estimated benefits of $PM_{2.5}$ reductions are now the largest category of quantified benefits.

The most important change in the assessment of Title IV benefits is for human health. Studies published in the last 15 years have shifted the focus of expected health benefits from acid aerosols to $PM_{2.5}$ (of which acid aerosols are one component). The evidence of an effect of $PM_{2.5}$ on mortality and morbidity is the basis of the 1997 NAAQS for $PM_{2.5}$, and implies substantial health benefits from Title IV required reductions in SO_2 and NO_x emissions. Research since 1990 has also revealed that some of the environmental problems associated with SO_2 and NO_x emissions are more challenging to resolve than originally thought. It will take substantially more reductions in emissions to achieve the desired environmental benefits, especially with regard to the effects of acid deposition and nitrogen deposition. Given the lower than expected costs of Title IV and the higher than expected benefits, further reductions in emissions of SO_2 and NO_x from the electric power sector are justified.

2. Emissions reductions

SO_2 and NO_x emissions from power plants have declined as expected with the implementation of Title IV. The US EPA estimated emissions and costs using the 2002 Integrated Planning Model (IPM), which is a multiregional model of the US electric power sector.[1] The IPM provides forecasts of least-cost capacity expansion, electricity dispatch, and emission control strategies for meeting energy demand and environmental, transmission, dispatch, and reliability constraints. The IPM evaluates the cost and emissions impacts of proposed policies to limit emissions. The scenario for 2010 without Title IV includes all existing and new source emission control standards for SO_2 and NO_x set before 1990, and a less efficient NO_x control technology option for future Title I compliance. The scenario with Title IV imposes a system-wide SO_2 emissions cap with trading and banking and includes several available fuel switching and emission control options. Retrofit combustion control options available for Title IV NO_x compliance are also included.

Fig. 1 shows annual SO_2 emissions by region for 1990 and 2000, and estimates for 2010 'with Title IV' and 'without Title IV' scenarios. In all regions, emissions are expected to be lower in 2010 than they would have been without Title IV, and lower in most regions in 2010 than they were in 1990. A similar regional pattern exists for NO_x emissions from power plants. Although there has been concern that the trading program might allow emissions to remain high or to increase in some locations, power plant emissions have remained low in regions where they were low in 1990, and the largest reductions have occurred in regions where emissions were the highest.

A key uncertainty in estimating Title IV benefits is projecting what levels of emissions would have been in the absence of Title IV. Benefits derive not just from reductions but also from prevention of increases. The 1990 assessment projections of SO_2 emissions in 2010 without a new control program ranged from an increase from 1990 levels to a reduction in emissions as large as that expected with a control program. The key uncertainties in this prediction were the remaining facility life for existing facilities not required to meet new source performance standards until major modification or replacement, rates of adoption of clean power production technologies, and expected growth in demand for electricity. The scenarios that predicted a large reduction in emissions by 2010 without Title IV assumed a more rapid replacement rate for older facilities, which would be retired or retrofitted with new control technology as required under New Source Review (NSR) when major modifications were made. Experience since 1990 has shown that most of these facilities have managed operations to avoid triggering NSR, resulting in facility life

[1] IPM was developed by ICF Consulting, Inc. For more information, see http://www.epa.gov/airmarkets/epa-ipm. IPM results reported here are based on model runs made in 2003 using the 2002 version of the model, which is documented in the US EPA publication, Documentation of EPA Modeling Applications Using IPM (V.2.1), March 2002. Adaptations were made to the 2002 base case assumptions for these model runs to calculate the counterfactual case for 2010 without Title IV and to estimate the emissions and costs for the Title IV case.

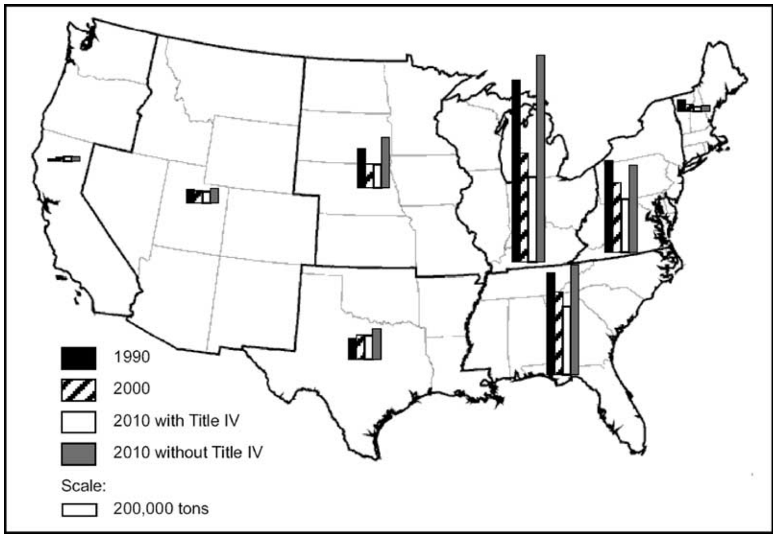

Fig. 1. Annual SO_2 emissions from the electric power industry by region. Source: calculated using data provided by US EPA, Clean Air Markets Division.

being extended longer and adoption of new control technologies being slower than many analysts predicted in 1990.

US EPA's current projections take this slower rate of facility retirement into account and show slightly increasing SO_2 emissions through 2010 in the absence of Title IV. We can be fairly confident now that without Title IV SO_2 emissions would not have been substantially reduced by 2010, but it is still difficult to estimate exactly what they would have been. Growing demand for electricity puts upward pressure on emissions, but this is expected to be offset somewhat by pre-1990 emission control requirements, efficiency improvements, and other economic factors. Demand growth assumptions used in this analysis are based on Energy Information Administration's 2001 estimates, with modifications for US EPA's assumptions that voluntary energy efficiency programs are going to be more effective.

Table 1 shows total annual emissions of SO_2, NO_x, and mercury from US power plants for selected years. Under Title IV, SO_2 emissions in 2010 are expected to be about 50% lower than they would have been. The reduction attributed to Title IV in 2010 is eight million tons; about 80% of this is the reduction from 1990 emission levels and the remainder is the prevention of increases.

NO_x emissions for 2010 are expected to be about 30% lower due to Title IV than they would have been. The NO_x reduction expected by 2010 due to Title IV is about one-half the total reduction in NO_x emissions from power plants expected by 2010 as a result of all CAAA requirements.

Shifts to using low-sulfur coal (which tends to contain less mercury) and installing controls to reduce emissions from coal-fueled power plants (selective catalytic reduction and scrubbers) have reduced mercury emissions, even though this was not planned as part of Title IV. Because of these changes, mercury emissions from power plants in 2010 are expected to be nearly 20% lower than they would have been.

Carlson et al. (2000) estimated about a six million ton reduction in SO_2 emissions in 2010 due to Title IV, based on projections using 1993 emission rates. They cite the conclusion by Ellerman et al. (2000) that switches to low-sulfur coal in 1991–1993 were motivated by economic

Table 1
Annual emissions from electric power plants in the US for selected years, and with and without Title IV in 2010[a]

Year	SO_2 (million tons)	NO_x (million tons)	Mercury (tons)
1980	17.3	6.0	No data
1990	15.7	6.7	No data
2000 with Title IV	11.2	5.1	48
2010 with Title IV[b]	9.3	5.0	42
2010 without Title IV	17.3	7.6	52
Reduction in 2010 due to Title IV[c]	8.0	2.7	10

[a] The source for NO_x emissions in 1980 and 1990 is US EPA, 2001 Data Base, DATAB01 Technical Support Document, Feb. 2002; for 2000 the source is US EPA, Clean Air Markets Division, Data and Maps (http://cfpub.epa.gov/gdm/). The source for SO_2 emissions for 1980, 1990, and 2000 is Data and Maps, augmented in 1980 and 1990 by the 2001 Data Base. The 2000 mercury emissions are in fact for 1999; an estimate for 2000 is not available. The 1999 estimate is from William Maxwell, US EPA (Memo to Maxwell from Jeffrey Cole, RTI, June 19, 2001). Emission estimates for all three pollutants in 2010 with and without Title IV are outputs of IPM.

[b] SO_2 emissions expected in 2010 with Title IV are somewhat above the permanent cap because the electric power industry is expected to have a few 'banked' allowances remaining. Facilities were allowed to 'bank' unused emissions allowances if they made greater reductions than required in the early years of the program as the cap was being gradually lowered. The banked allowances are expected to be fully used within a few years after 2010. NO_x emissions estimated 'with Title IV' reflect reductions due to Title IV requirements only and do not reflect reductions also expected under Title I.

[c] Differences do not exactly match 2010 totals due to rounding.

factors and not the result of Title IV emission reduction requirements taking effect in 1995. The deregulation of railroads resulted in lower transportation costs for low-sulfur coal from the Powder River Basin, making this coal source less costly for some power plants in the Midwest. Simultaneously, plant operators found cost-effective ways to adapt their boilers to use different coal types, which had been expected to be more expensive. The US EPA's projections of SO_2 emissions in 2010 without Title IV have been revised to reflect these circumstances. They are based on IPM model runs that allow coal-fired generation units to select the most economic coal supply, including Powder River Basin coal, that is available and can be used by various types of boilers, based on technical evaluation of coal usage in 2002. Using these assumptions US EPA obtained about a one million ton smaller estimate of the reduction in SO_2 emissions due to Title IV in 2010 compared to their previous results (US EPA, 1995).

3. Costs

The US EPA used IPM to estimate the total annualized cost of Title IV in 2010 to be about \$3 billion: \$2 billion for reducing SO_2 and \$1 billion for reducing NO_x.[2] Thus, the average annual cost per ton of SO_2 reduced is about \$250. This is comparable to other recently published estimates of annualized Title IV costs for SO_2 (NAPAP, 2004), and is slightly higher than the Ellerman et al. (2000) estimate of average annual costs for Phase I (1995–1999) of \$200 to \$225 per ton. Average costs are expected to be somewhat higher with the tighter Phase II cap that took effect in 2000. In the 1990 assessment, NAPAP reported a range of annualized average cost estimates from a variety of analyses using different assumptions and modeling tools for a 10 million ton reduction in SO_2 emissions. These ranged from about \$370 to over \$800, and averaged about \$550 per ton of SO_2 reduced (NAPAP, 1991). The current estimate of average cost per ton of SO_2 is below the low end of this range and is less than half the mean of average costs predicted in 1990.

Costs are lower than originally predicted primarily because flexibility occurred in areas that were thought to be inflexible and technical improvements were made that were not anticipated. Factors contributing to the lower costs include lower transportation costs for low-sulfur coal (attributed to railroad deregulation), productivity increases in coal production leading to favorable prices for low-sulfur and mid-sulfur coal, cheaper than expected installation and operation costs for smokestack scrubbers, and new boiler adaptations to allow use of different types of coal. It appears that Title IV has worked as expected to provide the flexibility and incentives for producers to find low-cost compliance options.[3] Banking opportunities also induced early reductions in emissions for some facilities. Harrington et al. (2000) compared estimates of actual costs of many large regulatory programs to predictions of those costs made while the regulatory programs were being developed and found a tendency for predicted costs to overstate the actual implementation costs, especially for market-based programs such as the SO_2 trading program. They cite technological innovation and unanticipated efficiency gains as key factors leading to lower than predicted costs. They note that unit costs are often more accurately predicted than total costs because predicted emission reductions are sometimes overstated, but they report that the predicted unit costs and total costs were both overstated for Title IV.

4. Effects on human health

The 1990 assessment of potential human health benefits focused on acid aerosols, acid deposition, and gaseous SO_2. Acid aerosols were suspected of being one of the toxic components of air pollutants that had been linked to elevated mortality rates, but the evidence was considered inconclusive. The assessment also examined the risk posed by the potential for acid deposition to mobilize harmful substances in the soil, causing them to enter the human food chain. Exposures via this pathway were then and still are very uncertain, difficult to quantify, and likely to affect limited populations who eat large quantities of freshwater fish. Most locations were already meeting the NAAQS for SO_2, and direct health benefits of further reductions in gaseous SO_2 were expected only for sensitive individuals residing near the power plants. Potential effects of changes in ozone concentrations (as a result of changes in NO_x emissions, which are an ozone precursor) on human health were acknowledged in the 1990 assessment, but not quantified.

The most dramatic change in the assessment of the human health benefits of Title IV is based on the mounting epidemiologic evidence published in the 1990s suggesting that particulate aerosols (PM_{10} and $PM_{2.5}$) as a whole, and not specifically acid aerosols, are harmful to human health. A large published literature, reviewed in detail by the US EPA (2004a) as part of the NAAQS process, now provides a strong basis for quantification of mortality and morbidity reductions expected as a result of the $PM_{2.5}$ reductions associated with SO_2 and NO_x emission reductions achieved by Title IV.

[2] All dollars are reported in year 2000 US dollars, unless otherwise noted. Costs are adjusted for inflation using the gross domestic product (GDP) deflator.

[3] Carlson et al. (2000) conclude that the cost-effectiveness of Title IV, relative to a command and control regulation that requires all units to install a specific control technology such as scrubbers, results more from the flexibility that allows plant operators to choose the method for reducing emissions than from allowance trading. However, they do estimate an additional cost savings due to trading.

This assessment uses the quantification methods currently used by the US EPA (1999, 2004b) to calculate central estimates of the human health benefits of $PM_{2.5}$ and ozone reductions, and updates an earlier assessment of the PM-related health benefits due to Title IV SO_2 reductions (US EPA, 1995; Ostro et al., 1999). First, expected emissions levels of SO_2 and NO_x for each electric power facility in the country for 2010, with and without the Title IV program, are input to the Regulatory Modeling System for Aerosols and Deposition (REMSAD), which estimates the transport and transformation of these emissions into ambient $PM_{2.5}$ concentrations.[4] Second, the REMSAD results, given on a 36 by 36 km grid covering the continental United States and southern portions of Canada, are used to calculate the differences in the annual average concentration of $PM_{2.5}$, with and without Title IV. Third, estimates of the 2010 population at each location and concentration–response functions selected from the available health effects literature are used to calculate the mortality and morbidity cases expected to be prevented as a result of this reduction in $PM_{2.5}$. Finally, estimates of the monetary value people place on these mortality and morbidity risk reductions are applied to these estimates.

A similar process to calculate the estimates of the health benefits of ozone reductions due to Title IV required NO_x emission reductions is used with the Comprehensive Air Quality Model with Extension (CAMx).[5] The area covered in the ozone analysis is the eastern half of the United States; CAMx covers the eastern and western United States in two separate models. Because about 90% of the reduction in NO_x emissions due to Title IV in 2010 is expected to come from power plants located east of the Mississippi River, only the eastern model was used for this assessment.

The estimates presented here are central estimates based on a careful selection of results from the published epidemiology and economics literature. The health effects included here are those amenable to economic valuation such as hospitalizations and days with symptoms. The US EPA (2004a) also summarizes evidence of potential physiological mechanisms that underlie the epidemiology results and may reflect additional health effects such as reductions in lung function, inflammation and infection, morphological changes, and altered host defense mechanisms.

The concentration–response functions used here are drawn from the available epidemiologic studies that use observed data on concentrations and health events to estimate the relationship between air pollution concentrations and the number of cases of each health effect in the population. The specific concentration–response functions used in this assessment were selected to be comprehensive but not overlapping. They represent central values, not the highest or lowest found in the literature. There are inevitable uncertainties and differences in opinion about how to interpret the available studies. For example, the US EPA (2004b) calculated a distribution of PM health benefits using reported confidence intervals from the original studies and obtained a 95th percentile a factor of 2 above the mean and a 5th percentile a factor of 4 below the mean. They also conducted sensitivity tests by changing key assumptions one at a time. If these analyses were repeated here, none would overturn the conclusion that the benefits of Title IV exceed the costs.

Fig. 2 shows the reductions in annual average $PM_{2.5}$ concentrations expected in 2010 relative to what they would have been in 2010 without Title IV. These results are consistent with the regional changes in power plant emissions attributed to Title IV and illustrate that the largest improvements in environmental quality are in locations where the effects of power plant emissions were the greatest before Title IV was implemented. The largest reductions in $PM_{2.5}$ concentrations are east of the Mississippi River where the mean reduction in annual average $PM_{2.5}$ is 1.4 $\mu g/m^3$. It is important to recognize that there is an inherent variability in air quality because of variability in weather and human factors. These estimates are for weather conditions of a representative year and actual conditions in any given year may differ.

These reductions in power plant emissions have implications for NAAQS attainment. The NAAQS for annual average $PM_{2.5}$ is 15 $\mu g/m^3$. Table 2 shows the results of an analysis of how many counties in the eastern half of the country would be in compliance with the NAAQS under the 'with Title IV' scenario in 2010 that might otherwise have been out of compliance: because of Title IV about 23 million more people can be expected to be living in counties meeting the $PM_{2.5}$ NAAQS. A similar analysis was conducted for the ozone NAAQS, which is 80 ppb (parts per billion) for the highest 8-h average each day. The results in Table 2 indicate that 23 million more people are living in locations that are in compliance with the ozone NAAQS because of Title IV. These analyses are for counties that are monitored for NAAQS compliance, which include most urban and suburban areas in the country. Only the eastern United States was included because Title IV is expected to have minimal effect on NAAQS compliance in the western United States.

4.1. Human health benefits of reductions in $PM_{2.5}$

The total value of the prevented $PM_{2.5}$-related health effects in 2010 is $108 billion for the United States, with an additional $6 billion for the REMSAD-covered Canadian population (Table 3). REMSAD calculates changes in $PM_{2.5}$

[4] REMSAD is a three-dimensional grid-based Eulerian air quality model designed to estimate annual particulate concentrations and deposition over large spatial scales. For more information, see http://remsad.saintl.com

[5] CAMx is a Eulerian three-dimensional photochemical grid air quality model designed to calculate the concentrations of both inert and chemically reactive pollutants by simulating the physical and chemical processes in the atmosphere that affect ozone formation. For more information, see http://www.camx.com/index.html

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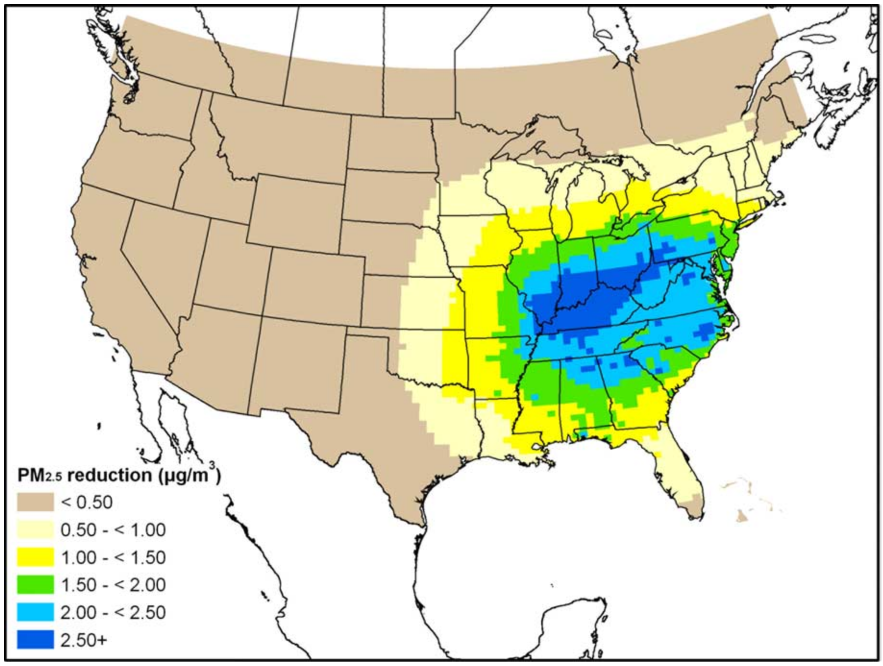

Fig. 2. Projected reductions in $PM_{2.5}$ (annual average) with Title IV from estimated concentrations without Title IV in 2010. Source: calculated using REMSAD results provided by US EPA, Clean Air Markets Division.

concentrations, as a result of changes in emissions in the United States, for the continental United States and for southern portions of Canada where about 80% of the Canadian population resides. The estimated 2010 health benefits in the Unites States and Canada include 18,000 deaths prevented, 11,000 new cases of chronic bronchitis avoided, and 24,000 nonfatal heart attacks prevented.

All of the health effects quantified represent adverse effects, but the mortality estimates play a particularly important role in the benefits analysis, making up about 90% of the total value of the PM-related health benefits. Evidence of a statistically significant relationship between $PM_{2.5}$ and mortality comes from short- and long-term exposure studies. Only the long-term studies can determine the full effects of exposure to ambient $PM_{2.5}$ and their results suggest that the mortality risk associated with $PM_{2.5}$ represents a substantial shortening of life for those affected. This analysis uses results from a recently published long-term exposure study (Pope et al., 2002), which is based on the largest cohort and longest follow-up period used to date. Other long-term exposure studies have reported both higher and lower effects of $PM_{2.5}$ on mortality.[6]

The concentration–response functions from short-term exposure studies show an effect on mortality that is smaller than the long-term exposure functions, and some earlier assessments of the benefits of Title IV averaged these functions to calculate a central estimate of PM-related mortality benefits (Burtraw et al., 1998; Ostro et al., 1999). The long-term exposure studies have now been re-analyzed (Krewski et al., 2000) and extended with larger data sets (Pope et al., 2002) and the National Research Council (NRC, 2002) has concurred with the US EPA's decision to use the long-term exposure studies as the basis for the primary estimates of PM-related mortality risk. The NRC agreed with the argument that the long-term exposure study design captures a more comprehensive measure of the effects of PM than the short-term exposure study design, and therefore provides a better measure of the full effect of PM on mortality risk.

An important finding reported in the literature is that some amount of health risk is observed over the entire range of $PM_{2.5}$ concentrations measured in US cities. The benefits estimated here assume that any reduction in $PM_{2.5}$ concentrations resulting from Title IV reduces health risk regardless of whether the location otherwise meets the NAAQS for $PM_{2.5}$. This is consistent with the assumptions the US EPA is using in their regulatory impact analyses and is supported by the NRC (2002). This also suggests policies that create incentives to continue finding more cost-effective ways to lower $PM_{2.5}$ concentrations will benefit public health regardless of whether the $PM_{2.5}$ NAAQS are met.

The economic measure of value that captures all the reasons why people value reductions in health risks is called

[6] Important differences of opinion on how to interpret these results remain. The US EPA (2004b) conducted a pilot expert elicitation study with five experts and found that several had concerns that the physiological mechanism underlying these findings is not fully known. Each expert provided a probability distribution for the effect of PM on mortality, and some gave greater weight to the possibility of no causal effect because of this concern. Thus, when responses from the five experts are pooled, the median effect is about one-half the value used here. If this were used as the central estimate, the Title IV PM health benefits would be about $60 billion.

Table 2
Effects of Title IV on NAAQS attainment in 2010 in the eastern half of the United States

	$PM_{2.5}$ annual average NAAQS		Ozone 8-h NAAQS	
	Number of counties	Population	Number of counties	Population
Not expected to be in NAAQS attainment under the 'without Title IV' scenario in 2010	153	60 million	226	78 million
Not expected to be in NAAQS attainment under the 'with Title IV' scenario in 2010	61	37 million	116	55 million
Expected to be in attainment because of Title IV (difference between row 1 and 2)	92	23 million	110	23 million

This analysis covers about 75% of the US population, and captures most locations where Title IV causes substantial reductions in $PM_{2.5}$ and ozone precursors. Source: calculated by the authors using data provided by US EPA, Clean Air Markets Division.

Table 3
National estimates of annual (2010) health benefits as a result of Title IV related $PM_{2.5}$ reductions

Avoided health effects	Number of cases of avoided health effects[a]		Monetary value (millions US 2000 dollars)	
	US	Canada	US	Canada
Mortality (adults)	17,000	1000	$100,169	$6002
Infant mortality (children less than 1)	100	5	$751	$28
Chronic bronchitis (adults)	10,400	600	$4056	$218
Nonfatal heart attacks (adults)	22,800	1200	$1917	$101
Respiratory hospital admissions (all ages)	8300	400	$123	$7
Cardiovascular hospital admissions (adults)	10,800	600	$233	$13
Emergency room visits for asthma (children)	14,100	600	$4	$0.2
Acute bronchitis (children)	26,600	1100	$10	$0.4
Asthma exacerbations (children with asthma)	28,200	1200	$1	$0.1
Upper respiratory symptoms (children with asthma)	338,200	15,200	$9	$0.4
Lower respiratory symptoms (children)	287,300	12,200	$5	$0.2
Minor restricted activity days (adults)	12,130,300	636,100	$643	$34
Work loss days (adults)	2,090,400	109,600	$228	$12
Total monetary value			$108,148	$6416

[a] Rounded to nearest 100. Source: calculated by the authors using REMSAD results provided by US EPA, Clean Air Markets Division.

willingness to pay (WTP). WTP is a measure of the monetary tradeoffs people are willing to make in exchange for a reduction in risk, and it is expected to reflect the value people place on all the financial and nonfinancial implications of health risk, including medical costs, lost income, and quality of life. Over the last several decades, economists have developed and refined techniques to estimate the WTP for reducing health risks. All the studies use either actual observed behavior (revealed preference studies) or responses to hypothetical scenarios presented to research subjects (stated preference studies). WTP estimates are used here for the monetary valuation of mortality and morbidity benefits when these estimates are available from the literature. For a few morbidity effects there are no WTP estimates available; in these cases cost of illness measures are used. These include only medical costs and value of time lost and are therefore expected to understate WTP.

The available literature suggests mortality risk reduction has a high monetary value, as would be expected, but there is considerable uncertainty about the best estimate of the value of mortality risk reduction in this circumstance. Most empirical studies on the value of mortality risk reduction have examined wage differences associated with different levels of on-the-job risks of accidental death. Viscusi and Aldy (2003) reviewed these studies and concluded that the most credible range of values for a reduction in annual mortality risk of 1 in 100,000 is between $50 and $120, with a median of about $70. Stated preference studies have examined values for mortality risk reduction via automobile safety, preventative health care, and other means, and the most credible range of results is between $10 and $60 per 1 in 100,000. A central estimate drawn from both types of studies and used in recent US EPA (2004b) analyses is about $60 per 1 in 100,000.[7] The average per capita risk reduction calculated for Title IV in 2010 is about 6 per 100,000, thus the average per capita value is about $300.[8]

[7] These values are often reported as the value per statistical life (VSL), the aggregate value for a risk reduction summed over enough people that one death is prevented. In this example, a value of $60 per 1 in 100,000 risk reduction is equivalent to a VSL of $6 million. Following the procedure used by the US EPA (2004b), we have adjusted the value for expected real growth in income using an income elasticity for WTP of about 0.4, which is consistent with results reported by Viscusi and Aldy (2003). The VSL starting point used by the US EPA (2004b) is $5.5 billion in 2000 dollars, with an income basis of 1990 consistent with the underlying literature.

[8] The PM-related mortality valuation is adjusted for an expected lag between a reduction in concentrations and the reduction in risk. The lag used by the US EPA (2004b) spreads the benefit over 5 years using a 3% discount rate.

All the literature reviews on monetary values for risk reductions do not reach the same conclusions about the best estimates for policy applications. For example, Mrozek and Taylor (2002) report one of the lowest mean monetary values for mortality risk among recent reviews of this literature. After reviewing the labor market studies, they concluded that many of the studies did not adequately control for inter-industry wage differentials and therefore overstated the value of mortality risk reduction. After making correcting adjustments, their results suggest a central value that is about half the value used here. If this value were used, the health benefits of Title IV would be about $50 billion in 2010; still an order of magnitude greater than the costs.

A previously published estimate of the health benefits of the Title IV-related PM reductions in the eastern United States was about $40 billion for 2010 (in 1995 dollars) (US EPA, 1995; Ostro et al., 1999). Adjusting for inflation and differences in the calculation methods (primarily a higher monetary value for mortality risk reduction) brings the previous estimate to about $60 billion. The remaining difference results primarily from higher estimates of the reduction in $PM_{2.5}$ concentrations. Reasons why the new estimates of reductions in $PM_{2.5}$ are larger include (1) they are based on mean rather than median concentrations, (2) they reflect reductions in NO_x emissions as well as in SO_2 emissions, and (3) they are derived using a different air quality model.

Burtraw et al. (1998) report annualized 2010 estimates of the costs and PM-related health benefits of Title IV that are both about half those presented here. They used a similar conceptual approach to estimate costs and benefits, but made some different literature selections for specific benefit function values and used different models to calculate costs, emissions, and air quality changes. These all caused differences in the results, but the primary reason for their substantially lower estimates of costs and benefits is that they obtained a substantially different estimate of what SO_2 emissions from power plants would have been in 2010 in the absence of Title IV.

4.2. Human health benefits of reductions in ozone

NO_x emissions are also a precursor to ambient ozone, a photochemical pollutant formed in the atmosphere in the presence of NO_x, volatile organic compounds (VOCs), and sunlight. Ozone is a criteria air pollutant and is linked to several types of morbidity effects and mortality. This was discussed but not quantified in the NAPAP (1991) assessment. Quantification is now feasible because it is possible to estimate changes in ozone concentrations over large geographic areas using the CAMx model and to extrapolate the episodic estimates from CAMx to the full ozone season (May–September) using routines available in BenMAP (US EPA, 2003).[9] Fig. 3 shows the estimated reduction in the ozone season average of 8-h ozone concentrations for the eastern United States.[10] The largest reductions are in the central Midwest and Atlantic Coast states. Ozone concentrations increase in a few locations, although the net health benefits are positive for every state as a whole. Increases in ozone formation when NO_x emissions are reduced are expected in some locations because of the complex atmospheric processes that result in ozone formation and depend, in part, on the local ratios of VOC/NO_x.[11]

Table 4 shows estimates of the health benefits of Title IV ozone reductions for the eastern United States. Some health benefits for the Canadian population, especially in Ontario and Quebec, are expected, but have not been quantified. The US EPA (2004b) analysis included calculations of potential ozone-related mortality only in sensitivity analyses, because of uncertainty in the literature about whether there is a statistically significant relationship between ozone and daily mortality. The key uncertainty is whether studies completed to date have been able to fully control for the potential confounding effects of $PM_{2.5}$, which is correlated with ozone in some locations during the summer months. Bell et al. (2004) report results of a recent meta-analysis of ozone and daily mortality in 95 US cities. Their analysis was fairly aggressive in controlling for as many potential confounding factors as possible, including daily PM concentrations. They conclude that although the relationship is not statistically significant in each city, the estimated effect of ozone on daily mortality is statistically significant when the data are pooled for all 95 cities. We therefore include in the central estimate of the health benefits of ozone reduction an estimate of the mortality benefit of ozone reduction based on the Bell et al. mean effect for the United States. As the estimates in Table 4 illustrate, the estimated total value of the health benefits of ozone reductions due to Title IV in 2010 is about $4 billion, and about 90% of this is for mortality risk reduction.

Hubbell et al. (2005) also use BenMAP to estimate the health benefits of meeting the 8-h ozone standard in the United States relative to actual ozone concentrations in

[9] BenMAP is a customized geographic information system program developed by Abt Associates for the US EPA (2003) that matches population to air quality model grids, calculates changes in air pollution metrics using data input from air quality models, and calculates changes in health effects.

[10] The western portion of the country, which is covered by a different version of the model, was not included for this analysis. Reductions in power plant NO_x emissions due to Title IV are expected to be relatively small in the western states (about 90% of the expected reduction is east of the Mississippi River) and therefore are likely to have only a small effect on ozone concentrations in the West.

[11] Nonlinearities in these relationships mean that evaluating the ozone effects of emission reduction programs one at a time may give different results than if the combined effect of all control programs that are happening concurrently is evaluated. This poses a particular challenge for program assessment.

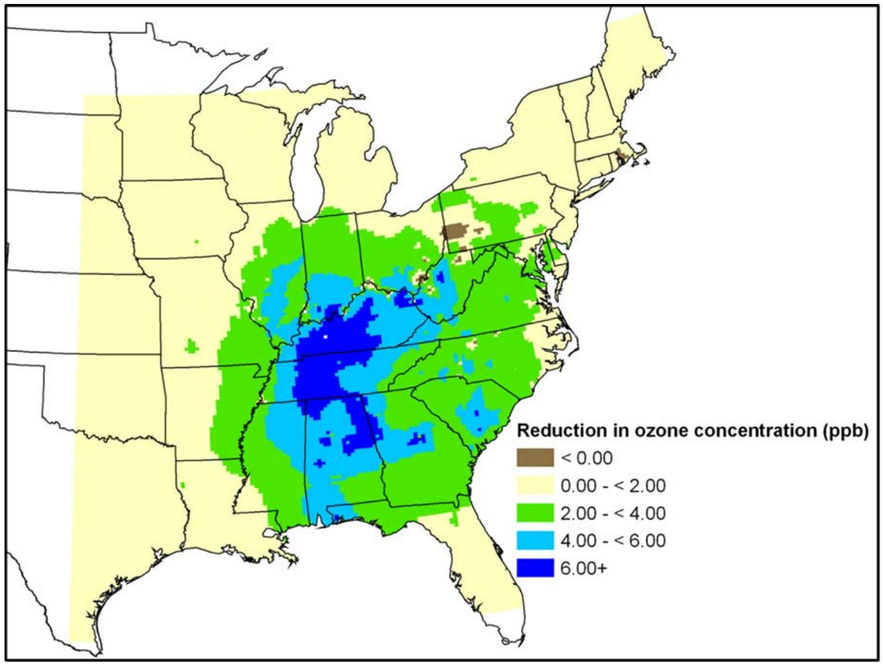

Fig. 3. Projected reductions in 8-h ozone concentrations (season average) with Title IV from estimated concentrations without Title IV in 2010. Source: calculated by the authors using BenMAP with CAMx results provided by US EPA, Clean Air Markets Division.

Table 4
Estimates of annual (2010) health benefits as a result of Title IV related ozone reductions in the eastern US

Avoided health effects	Number of cases of avoided health effects[a]	Monetary value (millions US 2000 dollars)
Mortality	700	$4101
Respiratory hospital admissions (age ≧ 65)	1500	$27
Respiratory hospital admissions (age ≤ 2)	1800	$14
Emergency room visits for respiratory illness	400	$0.1
School loss days	785,500	$59
Acute respiratory symptoms, minor restricted activity	1,612,100	$161
Worker productivity loss	n.a.	$22
Total monetary value		$4384

Source: calculated by the authors using BenMAP with CAMx results provided by US EPA, Clean Air Markets Division.
[a] Rounded to nearest hundred.

2000–2002. They calculate the reduction in ozone concentration necessary to meet the standard at each monitor. They presume no change in ozone concentrations at monitors that met the standard, which likely understates the regional ozone reductions that would result from emission reductions necessary to meet the standards at all monitors. They use the same concentration–response functions and monetary values as those used for this Title IV assessment, except for mortality they use the approach used previously by the US EPA (2004b) as a sensitivity analysis. The Bell et al. (2004) result used here to estimate mortality reductions for Title IV is a somewhat lower concentration–response function based on data from many more locations. Hubbell et al. report a central result for annual health benefits, averaged over 3 years, of about $6 billion when mortality is included.

4.3. Benefits of mercury reductions

The harmful effects of mercury emissions from power plants are primarily through deposition to water and soil and bioaccumulation through the food chain, which can cause high mercury concentrations in some species. When mercury enters water, microorganisms convert it to methylmercury, a highly toxic form of mercury. Because methylmercury is stable and accumulates through the food chain, the highest mercury concentrations are found in animals and fish that are highest in the food chain.

Human exposure to mercury is most often linked to fish consumption, and fish consumption advisories because of high mercury levels are common in the United States. Children of women with high mercury levels show developmental delays, lower neurological test scores, and delays and deficits in learning ability; about 8% of women of childbearing age in the United States have mercury levels in their blood that exceed the level considered safe.[12] Mercury can cause neurological and behavioral abnormalities in vertebrates, including humans, and has been linked to reduced reproductive success in fish and bird species. Elevated mercury (in hair samples) is linked to heart attack and heart disease deaths in adult men (Salonen et al., 1995). There is also evidence of a relationship between prenatal mercury exposure and blood pressure in children, which is a determinant of adult hypertension (Sorensen et al., 1999). Specific quantitative linkages between reductions in emissions and reductions in health and environmental injury are difficult because of the complex transport, bioaccumulation, and exposure patterns. Benefits accrue through reduced exposures and through the reduced need for fish consumption restrictions.

5. Effects on visibility

$PM_{2.5}$ in the air absorbs and scatters light as it passes through the atmosphere. Sulfate aerosols are particularly efficient at scattering light, which creates a hazy look to the sky, reduces the clarity of viewed objects, and reduces visual range. The 1990 assessment estimated changes in visual range at three eastern rural locations as a result of reductions in SO_2 emissions. Since that time the REMSAD model has been extended to calculate changes in visibility at all locations.

Analyses of visibility often use a measure of haziness called the deciview, an index that is near zero for pristine conditions and increases as visibility is degraded (Pitchford and Malm, 1994). A one deciview change represents about a 10% change in visibility, which is perceptible to the human observer. The US EPA calculated annual average deciviews using REMSAD based on estimated sulfate and nitrate aerosol concentrations in 2010 with and without Title IV. The reductions in deciviews expected in 2010 follow a similar geographic pattern to the reductions in $PM_{2.5}$ shown in Fig. 2. The mean reduction in annual average deciviews is about 1.4 east of the Mississippi River, about 0.9 in the central states, and about 0.1 in the mountainous West and along the Pacific Coast.[13]

Visibility conditions directly affect people's enjoyment of a variety of daily activities. Individuals value visibility where they live and work, where they go for recreation, and at sites of unique aesthetic value such as national parks. Economics studies have estimated monetary values held by visitors and the general public for changes in visibility at national parks, and for visibility where they live. NAPAP (1991) reported a preliminary assessment of value to the public based on estimates of visual range changes in a few rural locations. Subsequent visibility value studies (Chestnut and Rowe, 1990; McClelland et al., 1991) were later used to estimate the annual value of visibility changes in 2010 at national parks and residential areas in the eastern United States due to Title IV-induced sulfate aerosol reductions at about $4 billion (Chestnut and Dennis, 1997).

We calculated new estimates of the value of Title IV deciview changes using the estimation method currently used by the US EPA (2004b). This method uses the same original economics studies but with a new benefits transfer method (Smith et al., 2002) that adjusts the value per unit change when the results from an original study are extrapolated to different amounts of visibility change.

The original study of value for visibility improvements at national parks (Chestnut and Rowe, 1990) covered California, the Colorado Plateau, and the Southeast. The estimated annual value held by all households in the country for Title IV-related improvements in visibility at national parks and wilderness areas in these three regions is about $2 billion. Two more comprehensive estimates were also calculated, but these are considered sensitivity tests because there is considerable uncertainty about the accuracy of the extrapolations involved. The estimate of the total annual value for visibility improvement at all national parks and wilderness areas is about $3 billion. Adding estimates of WTP values by households for visibility improvements in locations where they live brings the total value of Title IV-related visibility improvements to about $5 billion.

6. Effects on natural resources

Three categories of natural resources in the United States have been injured by acid deposition and nitrogen deposition that result from power plant emissions: fresh-water lakes and streams, coastal estuaries, and forests. There is a considerable amount of new information about the nature of this injury and expected recovery since the 1990 assessment was completed, but comprehensive quantitative estimates of the benefits of Title IV for these natural resources have not been done.

Figs. 4 and 5 show estimates of the reductions in total (wet and dry) annual sulfur and oxidized nitrogen depositions expected in 2010 as a result of Title IV emissions reductions based on REMSAD estimates. The reduction in sulfur deposition is 30–50% from what it would have been in 2010 without Title IV over most of the central Midwest and Mid-Atlantic States, consistent with the 1990

[12] For more information see http://www.epa.gov/mercury

[13] A change of less than one deciview, measurable with instruments but perhaps not perceptible to the human eye, does not mean that these changes have no value. There may be value for small changes in the annual average for two reasons: (1) there may be perceptible changes on some days even if the change in the annual average is not perceptible, and (2) an individual regulation may lead to a small improvement in visibility that is imperceptible, but when the effects of all the regulations are combined there may be a perceptible change. Each regulation thus contributes to what is eventually a perceptible change.

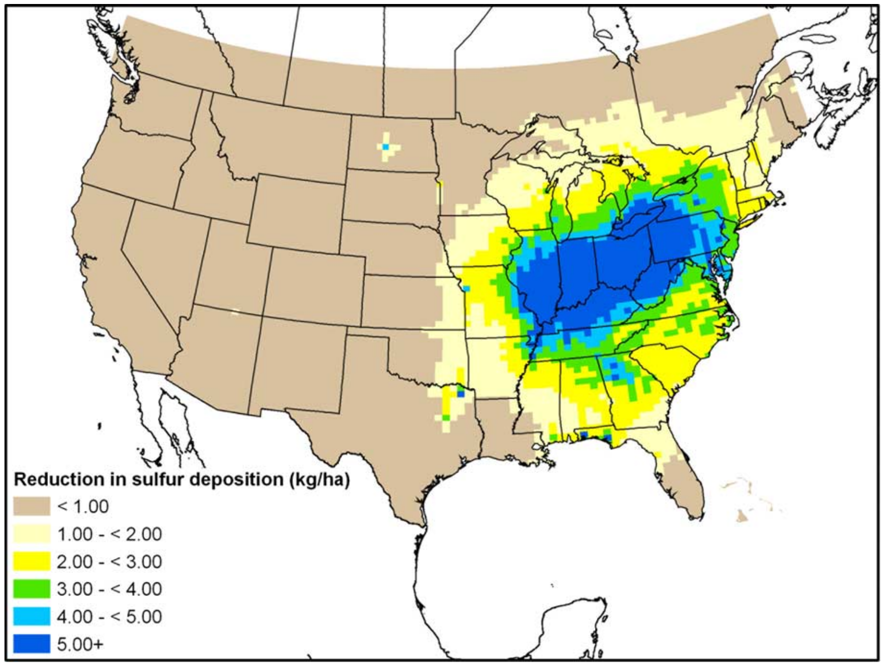

Fig. 4. Projected reductions in total annual (wet and dry) sulfur deposition in 2010 with Title IV from estimated deposition without Title IV in 2010. Source: calculated using REMSAD results provided by US EPA, Clean Air Markets Division.

assessment predictions. The reduction in nitrogen deposition is 25–30% throughout most of the East.

The way potential assessments of injury to natural resources are viewed has changed since the 1990 assessment, although methods for quantitative assessment remain incomplete. Since 1990 a more comprehensive conceptual approach has evolved in the literature that focuses on ecosystem services, including wildlife habitat, biodiversity, water cycling and purification, as well as recreation and aesthetic appreciation opportunities (Costanza and Folke, 1997). These services are valuable because of direct and indirect benefits. However, quantitative assessment remains problematic due to a lack of units of measure to gauge changes in the quality and quantity of

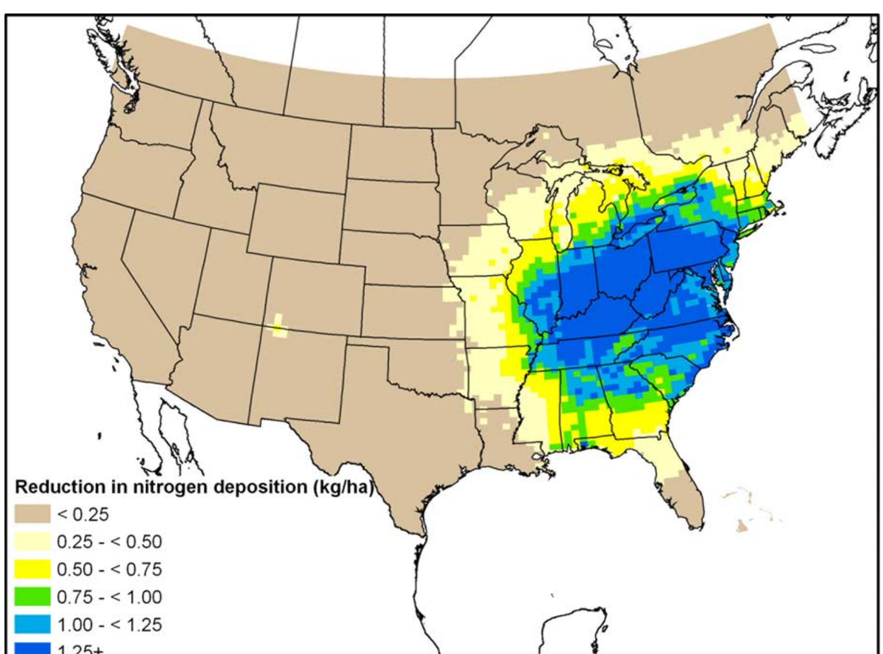

Fig. 5. Projected reductions in total annual (wet and dry) oxidized nitrogen deposition in 2010 with Title IV from estimated deposition without Title IV in 2010. Source: calculated using REMSAD results provided by US EPA, Clean Air Markets Division.

ecosystem services and a lack of dose–response relationships to indicate how quality and quantity may change as a function of changes in pollution exposures.

Another approach to estimating the value of improving the quality of natural resources is to ask respondents what they are willing to pay. A recent study reports that New York households are willing to pay an average of $45 to $100 annually to reduce the number of acidified lakes by 40% and improve forest health in the Adirondacks (Banzhaf et al., 2004). The 40% reduction in acidified lakes is an estimate of what would be achieved with an additional reduction in power plant emissions by an amount similar to the Title IV reductions. For all New York residents, this totals an annual value of $300 to $700 million. The biggest challenges with this approach are that the nature and implications of the injury have to be explained and understood by respondents and that values need to be determined for incremental improvements, such as those attributable to Title IV.

6.1. Freshwater lakes and streams

Certain locations identified during the studies in the 1980s showed moderate to severe acidification in freshwater lakes and streams, and other locations were considered vulnerable in the future if deposition rates continued unabated because of limited buffering capacity. Some of the affected lakes and streams showed loss of fish species and other aquatic life. Locations determined to have the highest rates of chronic acidification were in the Appalachian Mountains, especially in the Adirondacks in New York, and acid deposition from anthropogenic sources was the primary cause of this acidification (NAPAP, 1991).

Fig. 6 shows the percentages of lakes and streams estimated to have been chronically acidic in the mid-1980s. These are somewhat higher than those reported in the 1990 assessment, owing to improved understanding of how to measure acidification and more refined analysis and modeling using available water quality sampling data. Fig. 6 also shows estimates of acidification levels expected in 2030 with and without Title IV. These estimates are based on a longer time period than others in this analysis because changes in acidification are expected to lag many years behind changes in emissions.

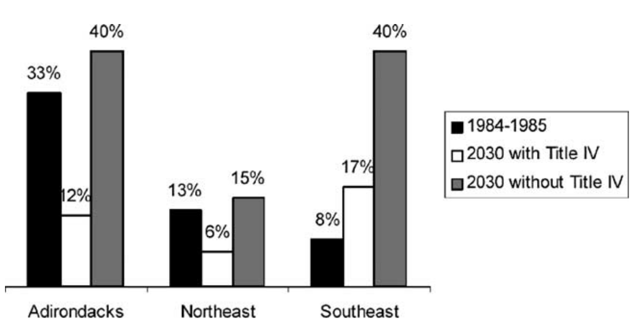

Fig. 6. Projected changes in percentage of lakes and streams with chronic acidification with and without Title IV. Source: NAPAP (2004), p. 58.

Research during the 1990s suggests that it will take longer for the eastern watersheds to recover than was estimated in 1990 (Herlihy et al., 1993; Driscoll et al., 1998). At deposition levels expected with Title IV fully implemented, acidification of lakes and streams in the Southeast will continue to increase, although not as much as without Title IV. The primary reason for the more pessimistic projections is that soils saturated with previous acid deposition will continue to release acids until levels in the soils are dramatically reduced, which is now expected to take decades. This situation is worse in the Southeast because of the sand and clay soils typical there.

Driscoll et al. (2003) review the trends in acidification status of all lakes in the Adirondack Long-Term Monitoring Program that was established in 1982 with 17 lakes and expanded to 52 lakes in 1992. They find significant decreases in acidification associated with reductions in sulfur deposition during the monitoring period (1982–2000), and a greater rate of improvement from 1992 to 2000 than earlier. If this higher rate of improvement continues, the predicted time it will take to reach chemical conditions that alleviate chronic acidification in Adirondack lakes is reduced from more than four decades to less than three. This is slightly more optimistic than the estimates reported in Fig. 6, but it is based on a linear extrapolation of current trends, which is uncertain. It is reassuring, however, to see confirmation of predicted improvements being reflected in the monitoring data.

The 1990 assessment included monetary quantification of the value of improvements in conditions for recreational fishing in New York and New England. Quantitative linkages were rather tentative, but the improvement in catch rate from a 10 million ton reduction in SO_2 emissions was estimated. Economics studies based on time and travel costs for recreational fishing trips estimated the implicit value of changes in catch rates and in the number of sites where fish stocks are available. The estimates of total annual value for improvements in recreational fishing were $12 million to $24 million (NAPAP, 1991). These estimates have since been improved with new modeling for estimating the changes in fish stocks and catch rates as a function of changes in emissions, and updated economics studies (Montgomery and Needelman, 1997). The US EPA (1999) reported estimates of annual value of improvements in conditions for recreational fishing in the Adirondacks of about $65 million for the reductions in acid deposition as a result of the 1990 CAAA, primarily Title IV. This may overlap somewhat with the value of all New York residents for ecosystem improvements in the Adirondacks, which would be expected to include values for improvements in recreational fishing held by anglers who live in New York. However, New York residents hold substantial value for ecosystem improvement regardless of whether they participate in recreational fishing (Banzhaf et al., 2004), and the fishing values include those who reside outside New York but travel to New York for fishing.

6.2. Coastal estuaries

The 1990 assessment included some consideration of the potential contribution of nitrogen deposition to eutrophication of coastal estuaries; however, the magnitude of the contribution was highly uncertain. Eutrophic conditions include algal blooms and low levels of dissolved oxygen that can stress or kill fish and shellfish and reduce areas of submerged aquatic vegetation that provide important habitat for many species. Analysis since 1990 suggests that nitrogen deposition from air emissions is a substantial contributor to excess nitrogen in watersheds, which is causing eutrophication in many US estuaries such as the Chesapeake Bay (Howarth, 1998; Valigura et al., 2001). This research indicates that the contribution of atmospheric deposition to the total nitrogen load in estuaries along the Atlantic and Gulf coasts is 15–30% in most cases. Nitrogen deposition as a result of NO_x emissions from power plants is a major, but not the only, source of atmospheric deposition of nitrogen.

6.3. Forests

The 1990 assessment included a summary of the evidence that acid deposition and ozone can harm trees and other vegetation, including slowed growth, increased mortality, and increased susceptibility to other stressors such as disease, insects, and drought. Although the chemistry is now fairly well understood, it remains difficult to estimate the specific changes that acid deposition causes in specific locations because local conditions vary and the interactions of pollutant and natural stressors are complex. Acids can cause leaching of nutrients (calcium, magnesium, and potassium) from leaves and needles and from soils, thus removing elements essential for tree growth. Acidification can also mobilize aluminum in the soil, which can interfere with nutrient uptake by plant roots. In addition, exposure to ozone has direct toxic effects on leaves and needles. The combined effects of all these changes can weaken trees, making them more susceptible to drought, temperature extremes, and diseases. Quantitative estimates of forest damage prevented by Title IV reductions are still not feasible, but evidence of damage exists for the high elevation red spruce in the Appalachian Mountains (DeHayes et al., 1999). Also of concern are changes in soils for high and mid-elevation spruce-fir forests in New York, New England, and the southern Appalachians, and for southern pines (Lawrence et al., 1999; Huntington et al., 2000). Recent evidence of damage to sugar maples in the Northeast has also emerged (Horsely et al., 2000).

The US EPA (1999) reports a total annual benefit to the US commercial timber sector of about $800 million and to grain crop producers of about $700 million in 2010 from improved yields due to ozone reductions as a result of the 1990 CAAA. Separate estimates of the portion of this benefit attributable to the Title IV have not been made. The US EPA (1999) reports benefits to worker productivity for strenuous outdoor labor of about $900 million for the CAAA ozone reductions. The Title IV worker productivity benefit estimate (Table 4) is about $22 million, so if the proportionality for timber and crop benefits remains, these benefits for Title IV are each about $20 million. The relative proportions of these benefits may vary for different programs due to differences in the geographic distribution of ozone concentration changes.

7. Effects of acid deposition on materials

Acid deposition causes damage to paint, galvanized steel, and limestone and marble, primarily through increased surface erosion. Particulate matter also causes soiling. The 1990 assessment discussed the evidence regarding these effects but did not provide quantitative estimates. Comprehensive estimates of the economic value of the Title IV reductions are difficult because the injury varies with the material and the local conditions. In many cases, the economic value is limited to the cost of repair or replacement of the material. Estimates of the additional household expenditures associated with higher levels of ambient particulate matter have been made, but the studies are out of date and were based on an older measure of particulates (total suspected particulates) that included large and small airborne particles.

Monuments and historic buildings are a category of materials with unique value, and a reduction in injury to these has a value beyond the replacement cost of the materials because people value the preservation of the original material. Marble and limestone are particularly susceptible to injury from acid deposition, including increased erosion and chemical changes (gypsum formation) that cause darkening of the surface and spalling. Morey et al. (2002) estimated that a typical household in the eastern United States values a 50% reduction in the rate of deterioration of marble monuments and historic buildings in Washington, D.C. at about $4 annually (or about $50 as a one-time payment). Whether this over- or underestimates the value of Title IV is uncertain because the change in the rate of deterioration due to specific acid deposition reductions remains difficult to determine. The estimated Title IV induced reduction in sulfur deposition in the Washington D.C. area is about 30% for 2010. If this translates to a 25% reduction in the rate of deterioration of monuments, the annual value for all households in the eastern United States would be about $100 million.

8. Conclusions

One of the most important uncertainties in the 1990 assessment concerned what emissions would have been by 2010 in the absence of the program. Some projections showed that other requirements of the Clean Air Act (primarily NSR) would have resulted in power plant emissions reductions as large as those required by Title IV by 2010 or soon thereafter. This might have happened if existing power plants gradually retired older equipment and installed new emissions control equipment, but the upgrading or retirement of the older power plants has been slower than the 1990 predictions. Thus US EPA's current estimates are that without Title IV, emissions through 2010 would have increased slightly from 1990 levels.

Table 5 summarizes Title IV costs and benefits. Important changes in our understanding of and ability to quantify the benefits of Title IV have occurred since the 1990 assessment. Benefits to human health now take a much higher profile because the contribution of SO_2 and NO_x emissions to the formation of $PM_{2.5}$ is substantial, and evidence of the harmful human health effects of $PM_{2.5}$ has emerged in the last 15 years. The central estimates of quantified benefits exceed costs by two orders of magnitude. Although important uncertainties exist in any specific estimate of the benefits, even if the estimates were calculated using more limiting assumptions and interpretations of the literature they still would substantially exceed the costs.

Comparing the current assessment of benefits of Title IV to the 1990 assessment teaches that ancillary benefits tend to be overlooked. With a problem-oriented focus such as acidification of lakes and streams, we tend to concentrate on that issue in the benefits assessment rather than consider all the related benefits that might be achieved with various pollution reduction strategies. Title IV benefits overlooked in 1990 included some 'upstream' of the acid rain problem, such as human health effects of $PM_{2.5}$, and some 'downstream,' such as estuary eutrophication from nitrogen deposition.

Title IV of the 1990 CAAA is on track to achieve the expected reductions in SO_2 and NO_x emissions from the electric power sector by 2010 for a cost that is substantially lower than originally estimated. The greater than expected benefits to human health, the greater vulnerability of natural resources and ecosystems, and the lower than expected costs all point to the conclusion that further reductions in emissions of SO_2 and NO_x from the electric power sector beyond those currently required by Title IV are warranted.

Table 5
Summary of annual benefits and costs of Title IV in 2010 (millions US 2000 dollars)

Quantified benefits[a]		
$PM_{2.5}$ mortality (US and southern Canada)	$107,000	
$PM_{2.5}$ morbidity (US and southern Canada)	$8000	
Ozone mortality (eastern US)	$4000	
Ozone morbidity (eastern US)	$300	
Visibility at parks (three US regions)	$2000	
Recreational fishing in New York	$65	
Ecosystem improvements in Adirondacks (New York residents)	$500	
Total annual quantified benefits		$122,000
Quantified costs		
SO_2 controls	$2000	
NO_x controls	$1000	
Total annual quantified costs		$3000

[a] These are central estimates but are subject to uncertainty and should not be interpreted as exact point values; we have therefore rounded for summary purposes. Many categories of expected benefits are not quantified due to insufficient data. Some, such as urban visibility, are quantified only as sensitivity tests due to uncertainty; these sum to about $4 billion. Other unquantified benefits include improved health and environment due to mercury reductions; improved health of natural forests and improved water quality in lakes, streams, and coastal estuaries from reductions in acid and nitrogen deposition; and increased longevity and reduced soiling of painted surfaces and stone materials.

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