The Health Impacts of Environmental Policy:
The North Carolina Clean Smokestacks Act

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The North Carolina Clean Smokestacks Act and related policies led to substantial decreases of emitted air pollutants from coal-fired power plants. Improved air quality was associated with statewide improvements in respiratory, cardiovascular, and cerebrovascular health in North Carolina. The effectiveness of environmental policies can be monitored for impact on both environmental and health outcomes.

Although the federal Clean Air Act of 1970 aimed to reduce air pollution by establishing standards for new fossil-fueled electric power plants, it left existing plants unregulated. Lawmakers assumed that older plants would be retired and replaced by cleaner, more modern plants, but the assumptions proved wrong. Most of the coal-fired power plants were still in operation 30 years later, and air pollution in surrounding and downwind regions affected by these power plants was a growing concern [1]. Two investor-owned utility companies in North Carolina housed 45 coal-fired electric generating units (EGUs) at 14 sites across the state, and Western North Carolina also suffered from airborne pollutants that blew into the region from the coal-fired power plants of the Tennessee Valley Authority (TVA) in East Tennessee. Due to widespread concerns about the impacts of air pollution on human health, the environment, and the economy in the Appalachian Region, North Carolina and 7 other states formed the Southern Appalachian Mountains Initiative in 1992. The findings from that innovative 10-year, multi-state, multi-partner study, and steadily growing worries and evidence of the impact of emissions from coal-fired power plants on air quality and public health, set the stage for the enactment in 2002 of a North Carolina law called the Clean Smokestacks Act. This law mandated significant reductions in emissions from coal-fired power plants, specifically requiring North Carolina's 2 investor-owned utilities to permanently reduce their total year-round nitrogen oxide (NO_x) emissions by 77% by 2009, and their sulfur dioxide (SO_2) emissions by 73% by 2013. In addition to harmful emissions reduction, the Clean Smokestacks Act helped North Carolina to reach its goal of improving visibility in the Smoky Mountains and other scenic vistas in the state by reducing the level of haze-causing contaminants. Furthermore, the steps used to reduce SO_2 and NO_x levels had the additional benefit of reducing acid rain in the state and lowering mercury emissions (the latter of which helps to decrease concentrations of mercury in ocean and freshwater fish species in Eastern North Carolina). Finally, it was expected that the emission reductions would have health benefits for the North Carolina population (as well as for the neighboring states) by significantly reducing the level of air contaminants.

Among other stipulations, the law directed North Carolina's attorney general to seek comparable reductions from upwind states and utilities. Under this provision, the attorney general sued the TVA in 2006 to force it to clean up its coal-fired power plants in the vicinity of North Carolina's western border. In 2011, TVA agreed to a court-approved settlement that achieved the Clean Smokestacks Act goal of reductions in TVA emissions that were comparable to the reductions required of the North Carolina utilities in terms of extent and schedule.

A decade and a half after the 2002 enactment of the Clean Smokestacks Act, the environmental results of the law are clear. The affected North Carolina utility companies have retired or scheduled retirement of a majority of the coal-fired power plants and have added SO_2 flue gas desulfurization (FGD) scrubbers and NO_x burners or selective catalytic or non-catalytic reduction (SCR/SNCR) technology on all the rest. In addition, one utility has built one large, new coal-fired power plant to operate far more efficiently using advanced emissions control technology [1]. The utilities have also invested in new gas-fired generating plants, as well as in renewable energy and energy efficiency incentive programs [1, 2]. The law set no specific caps for mercury, particulate matter (PM), or CO_2, but an additional benefit of closing or upgrading all the coal-fired plants for SO_2 and NO_x control was a significant reduction in mercury emissions. Specifically, mercury emissions dropped 87% between 2002 and 2012 [3]. As of 2014, the utilities collectively had reduced NO_x emissions by 83% and SO_2 emissions by 89% relative to 1998 emission levels [3].

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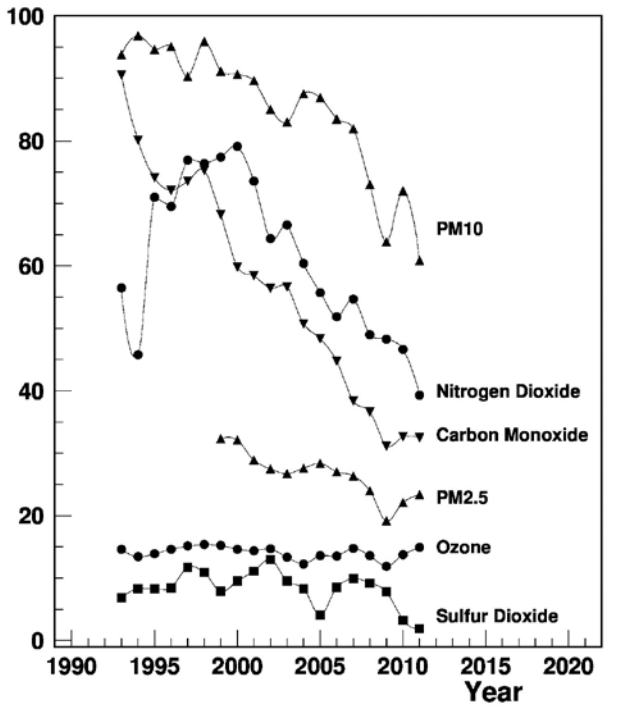
With the emissions reductions mandated by the Clean Smokestacks Act and various other air pollution control initiatives at the state and federal levels, and with the impact of other significant factors—such as the falling price of natural gas and the expanding use of renewables and energy efficiency—North Carolina's air quality has been able to sustain the improvements achieved since 2002. All areas of the state are now measuring in compliance with, or have reached attainment or maintenance status for, all air quality standards (oral communication between Ross and Mike Abraczinskas, director, NC Division of Air Quality, 2018). And, in the mountains, where the problem was acute in 2002, mountain views have improved dramatically. For example, at the Look Rock observation ledge overlooking the Great Smoky Mountains National Park the National Park Service reports that visual range has improved from 9 miles to 31 miles even on the worst haze index days (ie, on the worst 20% of days for visibility, when air pollutants as well as relative humidity and other physical factors affect visibility) (oral communication from Abraczinskas, referencing information from Jim Renfro, air quality specialist, National Park Service, 2018).

As stated at the outset, a primary driver for the passage of the Clean Smokestacks Act was the concern of many North Carolina citizens that outdoor air pollution was having an adverse effect on their health. People anticipated that improving air quality would also lead to improved health, and a variety of predictive studies, including modeling of potential health benefits, supported these beliefs. In the years since the enactment of the law, independent government agencies have accumulated large sets of data on both air quality and health. Although these datasets had not been previously juxtaposed, the existence of these sets of big data offered an opportunity to evaluate whether the anticipated and projected health benefits were being realized across the state during the same period in which air quality was improving. The Research Triangle Environmental Health Collaborative, which plans and holds meetings about important issues in the field of environmental health, conducted an environmental health "summit" that resulted in discussions of potential research involving the nexus of environmental and health sets of big data [4].

This work set the stage for collaborations between Duke University and the NC Division of Air Quality in the NC Department of Environmental Quality to study the dynamics of health outcomes in North Carolina populations and improving air quality as a result of air pollution control laws (including the Clean Smokestacks Act), regulations, and policies. In this collaborative work, investigators could demonstrate that the innovative North Carolina air pollution control policies, along with various national policies in the past few decades, have coincided with a measured reduction in the levels of these pollutants in outdoor air (see Figure 1). Further, the contribution of improved air quality to a descrease in deaths caused by respiratory diseases (see Figure 2) has been evaluated. Specifically, using monthly measurements from air-monitoring stations across North Carolina from 1993 to 2010, the investigators evaluated the associations between monthly fluctuations of the levels of air pollutants and age-adjusted death rates of respiratory diseases, adjusting for smoking prevalence and seasonal fluctuations of disease-specific respiratory deaths [5]. They calculated how a 1-unit reduction of air pollutant level coincided with a drop in death rates from emphysema, asthma, and pneumonia. Among gaseous pollutants, reductions of SO_2 levels correlated with lower death rates from emphysema, asthma and pneumonia; decreases in CO and NO_2 were significantly associated with lower emphysema and asthma mortality; decreases in fine particulates coincided with lower emphysema death rates (for $PM_{2.5}$) and reductions in asthma mortality (for PM_{10}) [5]. Temporal associations between the long-term dynamics of decreasing death rates of emphysema, asthma, and pneumonia and reductions of the levels of air pollutants in North Carolina support the hypothesis that improvement in air quality in the state contributed to the improved respiratory health of the population.

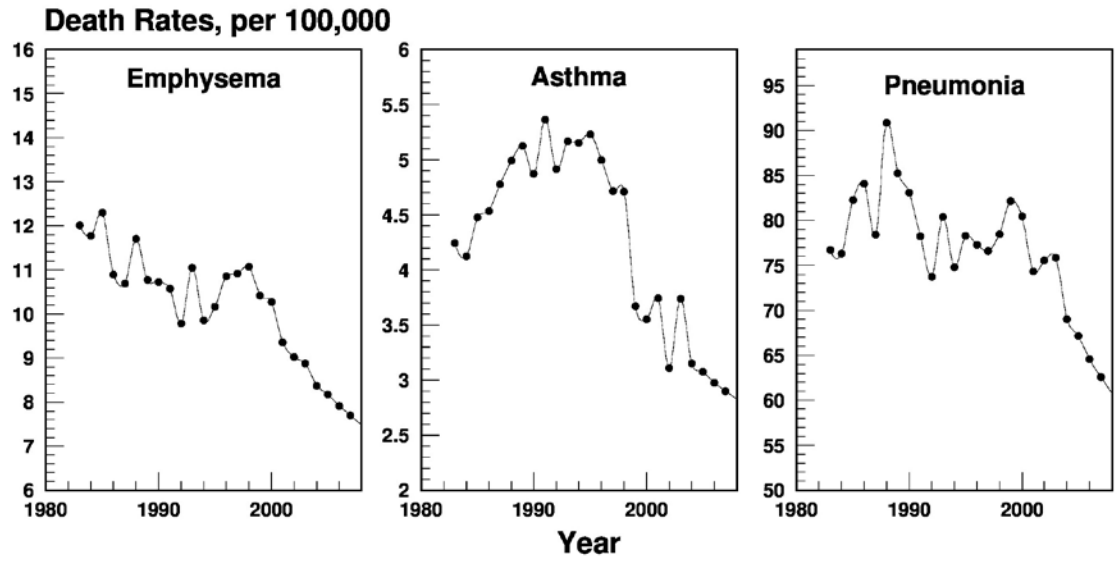
Subsequent independent studies have confirmed these results. University of North Carolina at Chapel Hill (UNC) researchers analyzed SO_2 and particulate sulfate ($PM_{2.5}$ sulfate) concentrations in the southeastern United

FIGURE 1.
Levels of Six Air Pollutants in North Carolina, 1993-2011



Source. International Journal of COPD 2014:9 613–627. Originally published by and reprinted with permission from Dove Medical Press Ltd.
Individual pollutants are placed onto a single graph by utilizing arbitrary units to enable a collective visualization of the trends.
PM, particulate matter [5].

FIGURE 2.
Trends of Death Rates of Emphysema, Asthma, and Pneumonia in North Carolina, 1983-2010



Source. International Journal of COPD 2014:9 613–627. Originally published by and reprinted with permission from Dove Medical Press Ltd. Mortality rates are age-adjusted to the 2000 North Carolina population [5].

States during 2002 through 2012 [6]. Their trend analysis showed that significant declines in SO_2 (-20.3%/year) and $PM_{2.5}$ sulfate concentrations (-8.7%/year) since passage of the Clean Smokestacks Act were correlated with the risk model estimates showing decreased risk of premature death attributable to $PM_{2.5}$ sulfate in North Carolina by about 63%, resulting in an estimated 1,700 (95%CI = 1500-1800) deaths prevented in 2012.

The studies of long-term effects of air pollution on health in North Carolina are innovative, as studies of the association between respiratory symptoms or respiratory diseases and long-term (rather than short-term) changes in air quality remain rare. Most previous long-term studies have focused on the association of PM with increased risk of COPD [7, 8], as well as hospital admissions for neurological disorders [9], and all-cause mortality [10]. Because poor health outcomes have been reported after exposure to air with levels of PM that fall below current national standards [11], some wonder if there is any safe threshold for outdoor air pollution. Consequently, studies have been proposed to investigate whether even low-dose exposure to ambient air pollutants can exacerbate the progression of COPD [12, 13]. The improving air quality in North Carolina could be the standard-bearer for these types of studies, as data from both air quality and all-cause and disease-specific mortality over decades are available.

Although the impact of cleaner air on respiratory health is impressive, the full impact of the cleaner air that resulted from the Clean Smokestacks Act and associated policies is not limited to a drop in the number of respiratory deaths; the reduction in morbidity associated with respiratory diseases including emergency department visits, hospitalizations, and lost work days also have enormous societal benefits. For example, significant health benefits of clean air can also impact cardiovascular and cerebrovascular health [14]. $PM_{2.5}$ has a link to cardiovascular disease possibly via accelerated atherosclerosis: long-term exposure to $PM_{2.5}$ was associated with an increased risk of higher intima-media thickness of the common carotid artery [15]. These findings help explain the associations between $PM_{2.5}$ concentrations and clinical cardiovascular events. Using approaches analogous to their studies of respiratory diseases [5], Duke investigators have recently found that older North Carolinians (over 65 years of age) had decreasing death rates of myocardial infarction, heart failure, and cerebrovascular disease (including stroke) from 1992 to 2010 that correlated with decreasing levels of SO_2, NO_2, $PM_{2.5}$, and PM_{10} in the air [17]. For example, a 10-unit reduction in SO_2 concentrations in the air (63% of sources of SO2 emission in North Carolina are from coal power plants [16]) led to a 5.5% reduction in myocardial infarction deaths, a 2.0% reduction in heart failure deaths, and a 4.7% reduction of cerebrovascular deaths [17]. As before, a limitation of this study is the reliance on retrospective data. Future studies using prospective analysis demonstrating the improvement in health with improving air quality will help support the policies that have benefited so many lives in North Carolina and will help our state envision new policies—state, regional, and local—that can provide additional benefits.

While longitudinal studies showed general reductions in respiratory, cardiovascular, and cerebrovascular mortality correlating with improved air quality in North Carolina,

there remains substantial regional variation in mortality associated with outdoor air pollution. For example, cross-sectional studies show increased mortality persists in communities geographically located near sources of power generation [18]. Although overall emissions from active coal power plants in North Carolina decreased from 1998 to 2013, all-cause, respiratory, and cardiovascular mortality among younger residents (aged 15-44 and 45-64) living in communities located in close proximity to coal power plants remains higher than in communities without nearby power plants (even when adjusted for socioeconomic characteristics, number of primary care providers, and smoking prevalence) [19]. Therefore, premature death and morbidity remains an important health issue in these communities and an assessment of factors that contribute to this issue is required.

To maintain a focus on population-based longitudinal and community based cross-sectional studies and to build on the progress made in the studies described above, public health agencies, universities, and other partners continue to collaborate to make large datasets available to researchers and the public. Some of the novel or emerging efforts aimed at making environmental and public health data, especially in large datasets, available to the public and researchers are shown in Table 1.

In conclusion, recent studies demonstrating the benefits to health from policies such as the Clean Smokestacks Act are proving to be significant in describing population health outcomes as a potential tool to fully appreciate the impact of changes in the environment. Furthermore, due to these innovative collaborative studies, North Carolina has emerged as a leader in the field, establishing a study direction focused on analyses of the health outcomes in residential populations and multiple environmental exposures, although other states are beginning their own efforts and analysis. For example, a recent California study demonstrated the positive health impacts of retiring power plants, describing a reduction in the proportion of preterm births in communities within 5 km of a retired power plant (from 7.0% to 5.1%) [20]. Further studies on health and the environment in North Carolina and efforts focused on cost-benefit analysis will allow us to estimate the costs and quantify the benefits of health improvements associated with cleaner air due to environmental policy. NCMJ

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TABLE 1.
Definitions of Environmental Justice Currently in Use by US and International Agencies and Organizations

Dataset name	Dataset brief description	Data accessed at:
NC Environmental Public Health Inventory	This inventory provides a listing of available state government databases that may be used for linking environmental hazards to health outcomes. Created by the Data Sharing Workgroup of the NC Environmental Health Collaborative, the inventory fulfills a recommendation from the 2010 Environmental Health Collaborative Summit, "America's Healthcare Policy Through the Lens of Environmental Health." The workgroup consisted of members from state environmental and public health agencies and academic partners.	http://epi.publichealth.nc.gov/oee/programs/eph_inventory.html
	The State Center for Health Statistics (SCHS) data are an example of data identified in the Environmental Public Health Inventory. The SCHS website includes a section specifically on how SCHS data are used for action.	For SCHS data see more information about what is available at: http://www.schs.state.nc.us/data/
Environmental Public Health Tracking Program	An initiative that the NC Division of Public Health has under development is the Environmental Public Health Tracking (EPHT) Program. This innovative new program will monitor and report environmentally related exposures and hazards that can affect human health throughout the state. The goals of the program are to: i) identify populations at risk from environmental exposures and hazards; ii) assist the evaluation of disease trends; iii) develop prevention strategies for controlling environmental hazards, exposures, and their resulting diseases; and, iv) assess existing public health policies and their effectiveness through surveillance and outreach. This is the program for the state with a plan to continue to submit the NC data to the national program. NC data can be accessed through the state and national websites.	http://epi.publichealth.nc.gov/oee/programs/epht.html NC has submitted data previously, which can be accessed by visiting: https://ephtracking.cdc.gov/showHome.action, clicking on "Access the new data explorer," and selecting North Carolina for the geographic area.
	Part of the NC EPHT Program would include submitting data to CDC twice a year so that we are included in analyses of national data. Asthma is an example of one of the indicators where data are available for NC.	
North Carolina Institute of Medicine Health Data	NCIOM has started an effort to make environmental, social, and health data available through an online portal.	http://nciom.org/nc-health-data/

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