North Carolina's Changing Energy Generation Profile and Reductions in Key Air Pollutants, 2000–2019

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BACKGROUND Coal combustion releases a number of airborne toxins. The North Carolina Clean Smokestacks Act (CSA) of 2002 required North Carolina coal-fired power plants (CFPP) to reduce nitrogen oxides (NO_X) emissions by 2009 and sulfur dioxide (SO_2) emissions to 2 benchmarks by 2009 and 2013.

METHODS We utilized publicly available databases from the Energy Information Administration and the Environmental Protection Agency to characterize North Carolina's electricity generation profile from 2000 until 2019 and evaluate corresponding NO_X and SO_2 emissions by sector over the same time period.

RESULTS Between 2000 and 2008 in North Carolina, approximately 60% of electric power was generated by CFPPs. Since then, North Carolina's electric power generation has transformed from predominant dependence on coal to approximately equal dependence on natural gas and nuclear power (each at ~ 30%), with coal close behind (~ 25%). Renewables have increased, although marginally relative to the rapid increase in natural gas. Despite the stark drop in reliance on CFPPs for energy in North Carolina and subsequent drop in emissions, CFPPs still contribute ~ 60% of SO_2 air pollution as of 2017.

LIMITATIONS This analysis relies upon electricity generation and emissions data self-reported by utilities and publicly available from federal agencies

CONCLUSIONS North Carolina's electric utilities met the 2009 and 2013 regulatory benchmarks set by the CSA, which resulted in substantial reductions in SO_2 emissions from the fuel combustion electric generation sector. Still, CFPPs remain the primary utility-related and overall anthropogenic contributor of SO_2 air pollution in North Carolina.

Coal-fired power plants (CFPP) emit many criteria pollutants and hazardous air pollutants that are known to cause negative health outcomes [1]. From 1995 to 2011, approximately 50% of the United States' electricity was produced by coal combustion [2, 3]. The US Environmental Protection Agency (EPA) estimated that in 2012 more than 470 CFPPs burned over 800 million tons of coal in 47 states and Puerto Rico [4]. While coal contributed 44% of the electricity generated in the United States in 2011, coal combustion contributed the majority of the power sector's air pollution, including 98% of sulfur dioxide (SO_2) emissions, 86% of nitrogen oxides (NO_X) emissions, 94% of mercury (Hg) emissions, 86% of particulate matter with a nominal mean aerodynamic diameter less than or equal to 10 micrometers (PM_{10}) emissions, and 83% of particulate matter with a nominal mean aerodynamic diameter less than or equal to 2.5 micrometers ($PM_{2.5}$) emissions [5].

Criteria and hazardous air pollutants are predominantly regulated by the EPA via the 1970 passage of the Clean Air Act. The Clean Air Act requires EPA to set National Ambient Air Quality Standards for the 6 criteria air pollutants, including NO_X and SO_X. The EPA uses nitrogen dioxide (NO_2) as the regulatory standard indicator for the larger group of NO_X (e.g., NO_2, nitrous acid, nitric acid) [6] and SO_2 as the regulatory standard indicator for the larger group of SO_X (e.g., SO_2, sulfur trioxide) [7]. These standards are informed by scientific literature that evaluates short- and long-term health outcomes associated with each criteria air pollutant. The EPA has established causal relationships for short-term exposure to SO_2 and NO_2 and respiratory effects, while suggestive and likely causal evidence links long-term exposure to SO_2 and NO_2 with respiratory effects [6, 7]. Additionally, the evidence is suggestive of a causal relationship between exposure to NO_2 and cardiovascular effects, diabetes, cancer, poor birth outcomes, and mortality [6].

In 2002, North Carolina enacted regulation—The Clean Smokestacks Act (CSA)—that required CFPPs in the state to reduce air pollutant emissions [8]. Under this act, North Carolina utilities had to reduce emissions of 2 criteria air pollutants—SO_2 and NO_X—and, due to environmental and public health concerns about these air pollutants, were not allowed to depend on pollution credits used by other states

Electronically published May 5, 2022.

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N C Med J. 2022;83(4):XXX-XXX. 0029-2559/2022/83403

as allowed by federal rules. The North Carolina regulation stated:

> North Carolina's utilities must reduce actual emissions of nitrogen oxides (NO_X) from 245,000 tons in 1998 to 56,000 tons by 2009 (77% reduction). Utilities also must reduce actual sulfur dioxide (SO_2) emissions from 489,000 tons in 1998 to 250,000 tons by 2009 (49% reduction) and 130,000 tons by 2013 (73% reduction). This represents about a one-third reduction of the total NO_X emissions and a one-half reduction of the total SO_2 emissions from all sources in North Carolina [8].

The purpose of this report is to corroborate the effectiveness of North Carolina's CSA at reducing air pollution, specifically SO_2 and NO_X, within the state and assess a major policy aimed at benefiting environmental health.

Methods

We accessed multiple publicly available US federal government databases made available by the Energy Information Administration (EIA) and the EPA for this analysis. The EIA is housed within the US Department of Energy and designated as a principal statistical agency that "collects, analyzes, and disseminates independent and impartial energy information" [9]. We used the EIA's "Electricity Data Browser" to access net electric power generation data by source for North Carolina annually from 2001 to 2019 [10]. From the "Electricity Data Browser" dashboard, we downloaded data selected from categories nested as follows: *electric power*, *North Carolina*, *all fuels*, and *annual data*. We also downloaded data by *all sectors* and specific sources of electricity generation to determine the overall contribution of each sector: *electric power*, *all commercial*, *all industrial*, and *residential*. For the *electric power sector*, we collapsed the energy source data into 5 categories: coal, natural gas, nuclear, renewables (conventional hydroelectric, wind, utility-scale solar, geothermal, biomass), and other (petroleum liquids, petroleum coke, other gases, other). We did not include "hydroelectric pumped storage" in any categories because the net generation is negative since the category reflects storage rather than use. We then calculated the annual contribution of each of the 5 *electric power sector's* sources as a percent of the total contribution.

We used EIA's "Layer Information for Interactive State Maps" to generate a map of power plants with greater than 1 megawatt (MW) capacity in North Carolina by their 2019 energy source and total generation capacity [11]. The EIA used Forms EIA-860, EIA-860M, and EIA-923 to create the 2019 US power plants shapefile we adapted for this analysis. We restricted the EIA power plants shapefile to plants in North Carolina, and then created separate shapefiles for each energy source category to display the type and capacity of each power plant. We defined the energy source categories as coal, natural gas, nuclear, renewables (biomass, hydroelectric, wind, solar), mixed use, and other (petroleum, other).

To create a similar map for power plants in North Carolina in 2001, we used EIA's Form EIA-860 for 2001 to identify the power plants with > 1 MW capacity in operation during that reporting year [12]. We used the reported energy source to create the energy source categories that matched the 2019 EIA shapefile (i.e., biomass, coal, geothermal, hydroelectric, hydroelectric pumped storage, natural gas, nuclear, petroleum, solar, wind, other). For each power plant, we summed the net summer capacity by energy source over all electricity-generating units. The energy source with the largest net summer capacity for each power plant was considered the primary energy source for that plant.

From the EIA database for 2001, we extracted geographic coordinates to map US power plants in North Carolina. Because specific locational information for power plants was not publicly available online from Form EIA-860 until 2012, we used the 2019 Form EIA–860M and the 2012 and 2019 Form EIA–860 to get the geographic coordinates. This allowed us to create a map of power plants for 2001 similar to the map we generated for 2019. We first matched the 2001 US power plant codes (N = 5019) with the latitude and longitude data provided in the 2019 Form EIA–860M. For the power plants from 2001 that were unmatched (n = 134), we used the geographic coordinates from the 2019 Form EIA–860 to match an additional 18 and the geographic coordinates from the 2012 Form EIA–860 to match an additional 5, leaving n = 111 ungeocoded US power plants. Of these, 5 were located in North Carolina; we manually looked up their location. We then created a 2001 US power plants shapefile using the geographic coordinates for the US power plants (n = 4912), then restricted to the plants in North Carolina, and then followed the same procedures as stated for making the 2019 map to display n = 103 mapped power plants in North Carolina for 2001.

We used the US EPA's National Emissions Inventory (NEI) to calculate the reported sector-specific emissions for SO_2 and NO_X in North Carolina [13]. The NEI is "a comprehensive and detailed estimate of air emissions of criteria pollutants, criteria precursors, and hazardous air pollutants from air emissions sources" released every 3 years [13]. It is developed using data provided by state, local, and tribal air regulatory agencies and combined with other data from EPA that include point, nonpoint, on-road, nonroad, and events (e.g., wildfires) [13]. We used the NEI Data Queries dashboard for 2008, 2011, 2014, and 2017, selecting: *North Carolina, all sectors*, and the 2 criteria air pollutants of interest—*NO_X* and *SO_2*. We defined the sector categories as: 1) Fuel Comb: Electric Generation; 2) Fuel Comb: Industrial Boilers, ICEs; 3) Fuel Comb: Other (including: Commercial/Institutional and Residential); 4) Industrial Processes; 5) Mobile: Non-Road (including: Aircraft, Commercial Marine Vessels, Locomotives, Non-Road Equipment); 6) Mobile: On-Road (including: On-Road Diesel Heavy Duty Vehicles, On-Road Diesel Light Duty Vehicles, On-Road Non-Diesel

Heavy Duty Vehicles, On-Road Non-Diesel Light Duty Vehicles); and 7) Other (including Agriculture, Biogenics, Bulk Gasoline Terminals, Commercial Cooking, Dust, Fires, Miscellaneous Non-Industrial NEC, Gas Stations, Solvent, Waste Disposal). We confirmed consistency of reporting by year within subsectors to verify that the subsectors were reported for all 4 NEI years analyzed. For subsectors not consistently reported, we determined that emissions contributions were nominal to the overall sector category and year. For example, *Solvent – Degreasing* was not reported for NO_X in 2008. However, the 2011, 2014, and 2017 reported emissions for *Solvent – Degreasing* were 8.9 tons, 7.8 tons, and 10.9 tons, respectively—negligible contributions to the overall 2008 NO_X NEI emissions profile (< 0.005%). We graphically illustrated SO_2 and NO_X emissions (tons) by sector by NEI year.

To illustrate changes in SO_2 and NO_X emissions by the fuel combustion electric generation sector in North Carolina over time, we accessed the "State Annual Emissions Trend" Excel file prepared by the US EPA for state reporting of Tier 1 criteria pollutants [14]. This data file is a more heavily processed and aggregated version of the year-specific NEI data downloads. We extracted the observations for *North Carolina*, *FUEL COMB. ELEC. UTIL.*, *SO_2*, *NO_X*, and years 1998 to 2019. Our filter criteria output had no missing data. The reported SO_2 and NOX emissions for 2008, 2011, 2014, and 2017 match the values we calculated from the NEI for "Fuel Comb: Electric Generation" sector described here.

We used R version 3.6.1, RStudio version 1.2.5001 [15], and ArcGIS version 10.5 for all processing and analyzing of data.

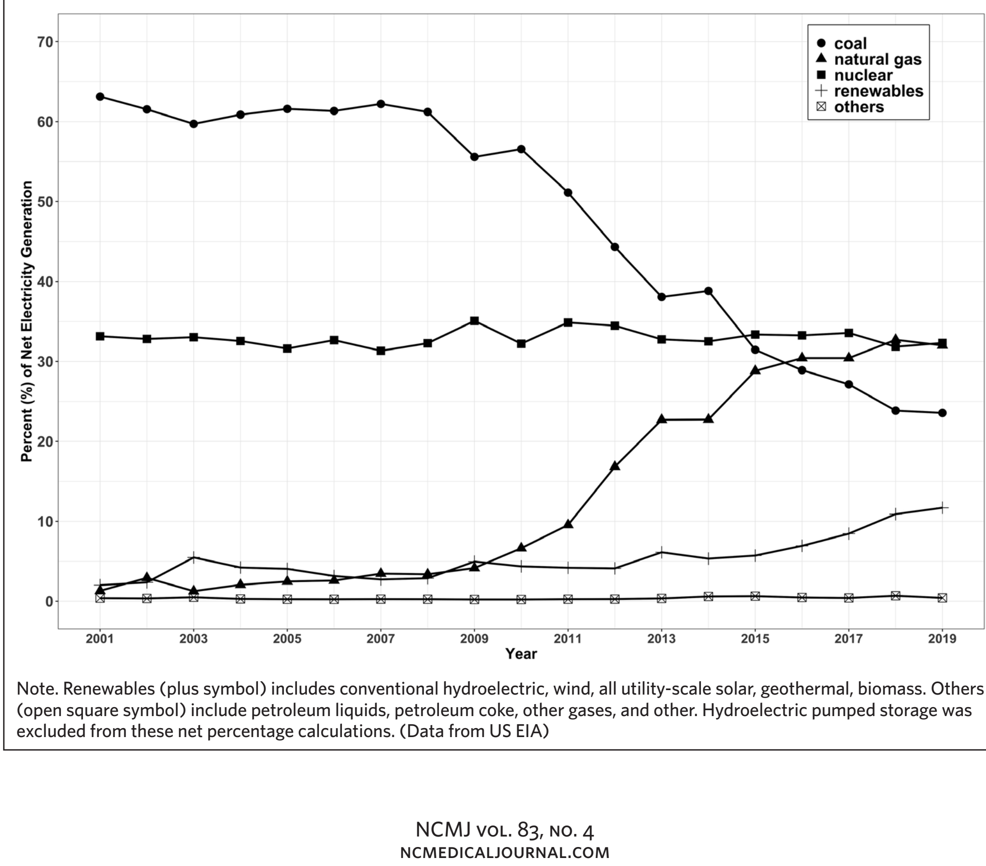
Results

Electricity Generation in North Carolina

Among all sectors in North Carolina that report generating electricity (i.e., electric power, industrial, commercial, and residential), the electric power sector has consistently accounted for approximately 98% of the net generation between 2001 and 2019. Within the electric power sector, North Carolina's annual net electricity generation has remained largely stable across this time period, although with a slight increase over time, with the minimum annual generation in thousand megawatt hours of 113,961 in 2001 and a maximum of 132,127 in 2018. Coal was the primary source of electric generation until approximately 2015. From 2001 to 2019 in North Carolina, the proportion of coal electric generation declined from ~ 60% to ~ 25%, natural gas electric generation increased from ~ 1% to ~ 30%, renewables increased from ~ 1% to ~ 10%, and nuclear electric generation remained stable at ~ 30% (Figure 1).

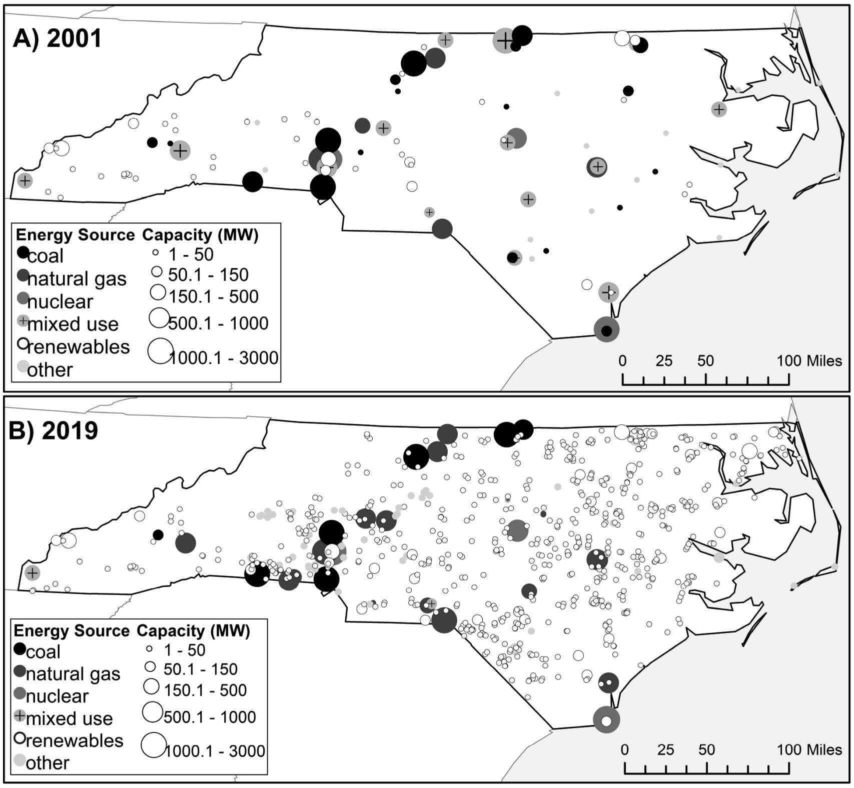
The number of power plants in North Carolina increased from 103 in 2001 to 745 in 2019, varying in energy source and capacity (Figure 2, Table 1). In 2001, a majority of the largest capacity power plants used nuclear or fossil fuels, especially coal. Eleven of the 14 mixed-use power plants used coal or natural gas as their primary energy source. In 2019, despite the proliferation of many small solar plants across North Carolina, the largest-capacity plants continue

FIGURE 1.
Percent Electric Power Generation by Source in North Carolina From 2001 to 2019



Note. Renewables (plus symbol) includes conventional hydroelectric, wind, all utility-scale solar, geothermal, biomass. Others (open square symbol) include petroleum liquids, petroleum coke, other gases, and other. Hydroelectric pumped storage was excluded from these net percentage calculations. (Data from US EIA)

FIGURE 2.
Power Plants in North Carolina by Energy Source Category and Capacity: A) 2001 and B) 2019



Note. Power plants with more than 1 MW capacity are shown. (Data from US EIA). Energy source category is indicated by grey scale color. Capacity is indicated by size of circle.

to rely on nuclear and fossil fuels, with 3 of the 4 mixed-use power plants relying primarily on coal and petroleum.

SO_2 and NO_X Emissions by Source Sector in North Carolina

Both SO_2 and NO_X emissions levels dropped over time between 2008 and 2017 based on the NEI estimates for the 2 criteria air pollutants. The majority of SO_2 emissions in North Carolina came from fuel combustion electric generation (Figure 3, Left). Within the fuel combustion electric generation sector, coal accounted for nearly all (> 98%) SO_2 emissions. NO_X emissions also declined within the fuel combustion sector, but unlike SO_2 emissions, overall reductions in NO_X emissions were primarily due to the on-road mobile sector (Figure 3, Right).

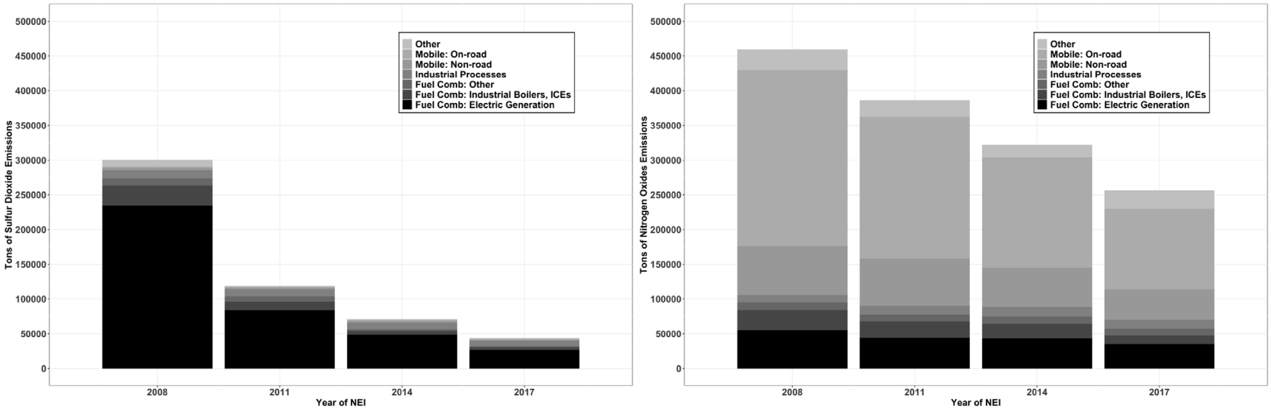
The North Carolina Clean Smokestack Act tasked North Carolina utilities with reducing emissions of NO_X and SO_2

TABLE 1.
Number of Power Plants in North Carolina by Energy Source in 2001 and 2019

Energy Source[a]	Subcategory	# in 2001	TOTAL by Energy Source in 2001	# in 2019	TOTAL by Energy Source in 2019
Coal	Coal	21	**21**	7	**7**
Natural gas	Natural gas	6	**6**	19	**19**
Nuclear	Nuclear	3	**3**	3	**3**
Other	Other	1	**14**	1	**45**
	Petroleum	13		44	
Renewables	Biomass	7	**45**	33	**667**
	Hydroelectric	38		39	
	Solar	0		594	
	Wind	0		1	
Mixed-use[b]		14	**14**	4	**4**
TOTAL			**103**		**745**

[a]The energy source categories and total by energy source matches the values represented in Figure 2.
[b]Mixed-use: For power plants that reported more than one energy source with greater than 1.5 MW.

FIGURE 3.
Sulfur Dioxide [LEFT] and Nitrogen Oxides [RIGHT] Emissions in 2008, 2011, 2014, and 2017 by Sector in North Carolina



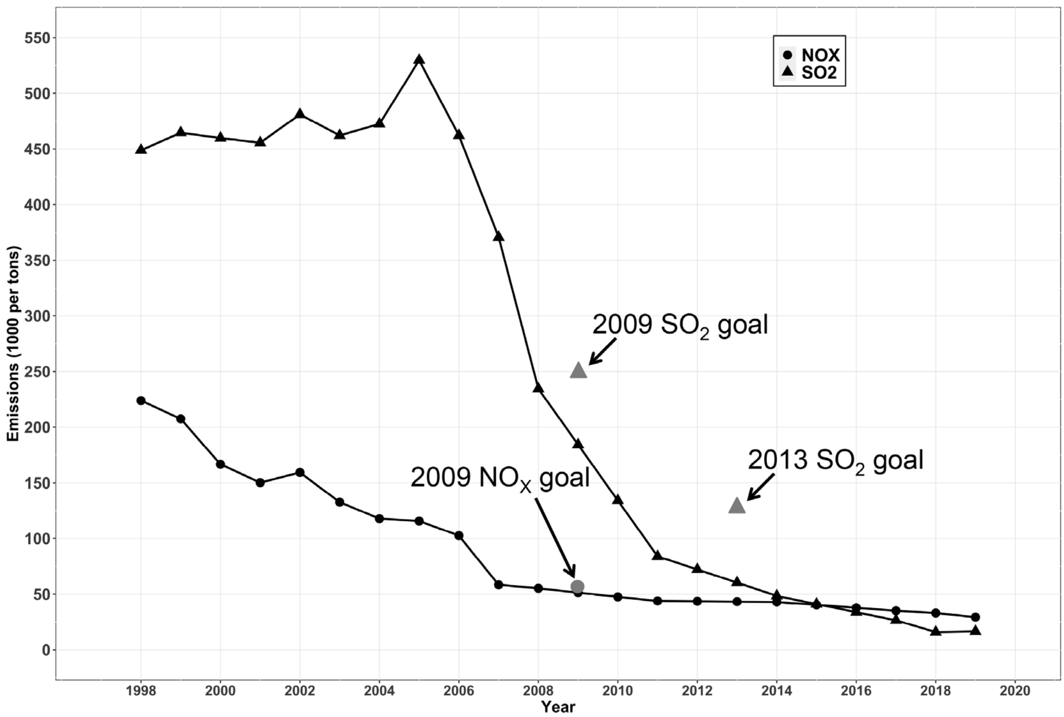
Note. Year of National Emissions Inventory = NEI. Sectors stacked in same order as the legend from light grey to black. (Data from US EPA's NEI)

by 2009 and 2013 benchmarks. Within the fuel combustion electric generation sector, specifically, the utilities met those regulatory requirements (Figure 4). In large contrast to the late 1990s/early 2000s, less SO_2 than NO_X was emitted by the fuel generation sector in 2019. Statewide, overall SO_2 emissions decreased primarily due to reductions in the fuel combustion electric generation sector, whereas overall NO_X emissions decreased primarily due to reductions in the mobile sectors.

Discussion

Over the past 20 years, North Carolina's energy generation has shifted away from coal toward natural gas, while dependence on nuclear power has been stable. Renewable energy has increased slightly over the past 5 years. While the number of solar power plants has increased dramatically from 0 solar plants of at least 1 MW in 2001 to 594 solar plants of at least 1 MW in 2019, the overall contribu-

FIGURE 4.
Sulfur Dioxide [TRIANGLES] and Nitrogen Oxides [CIRCLES] Emissions Annually from 1998 to 2019 by the Fuel Combustion Electric Generation Sector



The grey triangles and circle indicate NC Clean Smokestacks Act regulatory benchmarks in 2009 and 2013 for SO_2 (250,000 tons by 2009 and 130,000 tons by 2013) and NO_X (56,000 tons by 2009). (Data from US EPA's NEI) tion to North Carolina's energy profile remains small with all renewables contributing just over 10% of the net electricity generation in 2019. Statewide, the primary source of SO_2 is emissions from coal-fired power plants and the primary source of NO_X is mobile emissions; both have decreased over time. Importantly for public health, there has been a striking drop in SO_2 emissions, achieving a major goal of the North Carolina CSA of 2002. Health benefits associated with the CSA or the reduction of criteria air pollutants in North Carolina have been observed by 2 studies. Li and MacDonald Gibson (2014) confirmed a reduction of SO_2 from 2002 to 2012 and estimated that pollutant reductions decreased the risk of premature death by 63% in North Carolina [16]. Kravchenko and colleagues (2014) conducted an ecological study using monthly averages of pollutant concentrations measured across the state and monthly state-level death rates; they observed declines in emphysema deaths, asthma deaths, and pneumonia deaths associated with decreasing levels of SO_2 as well as other ambient air pollutants in North Carolina from 1993 to 2010 [17].

The electric utilities in the state achieved the NO_X and SO_2 regulatory goals set forth by the CSA through multiple strategies. To reach the 2009 benchmarks, many of the largest-capacity CFPP facilities incorporated selective catalytic reduction devices to reduce NO_X emissions and flue gas desulfurization equipment (FGD; i.e., scrubbers) to reduce SO2 emissions. The FGDs also capture hydrogen chloride, mercury, and particulate matter before emissions exit the stacks [18]. Hoppock and colleagues (2012) [19] argue that the investments in the early 2000s aided subsequent compliance with federal environmental regulations of the Cross-State Air Pollution Rule of 2011 [20] and the acid gas requirements of the Mercury and Air Toxics Standards [21]. To reach the 2013 SO_2 regulatory goal, many of the older and smaller-capacity > 150 MW CFPPs were retired because of the expense of retrofitting the stacks with necessary equipment [22], and most of these utility facility sites were then converted to natural-gas-fired power plants. Thus, due to either the installment of FGDs at CFPPs or the retirement of CFPPs, the CSA had the additional benefit of reducing other hazardous air pollutant emissions than SO_X and NO_X across the state.

It is important to remember that air pollution crosses state boundaries. Our study does not characterize the changes in air pollution emissions from power plants or other emission sources located in nearby states. We do not compare EPA criteria pollutant standard concentrations in North Carolina over the study period because that relies on ambient air pollution, which is driven by state-specific emissions as well as emissions derived and transported from outside of the North Carolina state boundary. Our study is focused on source emissions of 2 criteria air pollutants (SO_2 and NO_X) regulated by the CSA within the state of North Carolina; however, any reductions in air pollution from sources near the North Carolina border would likely enhance the reduction of ambient air pollution concentrations across the state. Kravchenko and coauthors (2018) described an additional aspect of the CSA that required North Carolina to hold upwind states and utilities accountable for comparable air pollution reductions, which resulted in court-ordered SO_2 and NO_X emission reductions from the CFPPs of the Tennessee Valley Authority [23].

Regardless of data limitations and access challenges, the available data effectively illustrate North Carolina's changing energy profile and improving air pollutant emissions for SO_2 and NO_X over the past 20 years. Despite North Carolina's closure of large CFPPs and proliferation of small solar plants, the net electricity generation within the state remains driven by nonrenewable sources, i.e., fossil fuels and nuclear. As North Carolina plans for its energy generation future, such as commitments made by Executive Order No. 80 (North Carolina's Commitment to Address Climate Change and Transition to a Clean Energy Economy) [24] and House Bill 951 (Energy Solutions for North Carolina) [25], the state should consider the co-benefits of implementing environmental regulatory policies for mitigating climate change and improving health outcomes across the state [23, 26].

Conclusion

North Carolina's CSA legislated reductions rather than trades to meet emission standards [8], which likely magnified emission reductions directly affecting North Carolina residents. North Carolina's CFPPs met the 2009 and 2013 regulatory benchmarks set by the CSA, resulting in substantial reductions in SO_2 air emissions emitted by the fuel combustion electric generation sector within the state. Since early 2000s, North Carolina's electric power generation has undergone a transformation from predominately dependent on coal to a considerable ramp-up of natural-gas-fired plants resulting in approximately equal dependence on natural gas and nuclear power over coal. Renewables have increased in the past 20 years, although marginally compared with the rapid increase in natural gas. NCMJ

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Acknowledgments

This work was funded in part by a training grant from the National Institute of Environmental Health Sciences (T32 ES007018). Thank you to Drs. Cory Keeler and Libby McClure for their ArcGIS and R software troubleshooting assistance.

Disclosure of interests. The authors have no conflicts of interest to disclose.

References

1. Bi X. 'Cleansing the air at the expense of waterways?' Empirical evidence from the toxic releases of coal-fired power plants in the United States. *J Regul Econ.* 2017;51(1):18–40. doi: 10.1007/s11149-016-9314-6
2. Epstein PR, Buonocore JJ, Eckerle K, et al. Full cost accounting for the life cycle of coal. *Ann N Y Acad Sci.* 2011;1219:73–98. doi: 10.1111/j.1749-6632.2010.05890.x
3. National Research Council. *Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use*. National Academies Press; 2010. Accessed: Nov. 23, 2020. http://ebookcentral.proquest.com/lib/unc/detail.action?docID=3439941
4. Hazardous and Solid Waste Management System; Disposal of Coal Combustion Residuals From Electric Utilities. *Fed Reg.* 2015;80(74):21301–21501. Accessed Nov. 23, 2020. https://www.federalregister.gov/documents/2015/04/17/2015-00257/hazardous-and-solid-waste-management-system-disposal-of-coal-combustion-residuals-from-electric
5. Massetti E, Brown MA, Lapsa MV, et al. Environmental quality and the U.S. power sector: air quality, water quality, land use and environmental justice. *Environ Sci.* United States. 2017. https://doi.org/10.2172/1339359
6. USEPA. Integrated Science Assessment (ISA) for Oxides of Nitrogen – Health Criteria (Final Report, 2016). *Fed Reg.* 2016;81(18):4910–4911. https://www.govinfo.gov/content/pkg/FR-2016-01-28/pdf/2016-01548.pdf
7. USEPA. Integrated Science Assessment (ISA) for Sulfur Oxides – Health Criteria (Final). *Fed Reg.* 2017;82(238):58600–58601. https://www.govinfo.gov/content/pkg/FR-2017-12-13/pdf/2017-26893.pdf
8. Clean Smokestacks Act (CSA). NC Department of Environmental Quality website. Accessed August 04, 2020. https://deq.nc.gov/about/divisions/air-quality/air-quality-outreach/news/clean-air-legislation/clean-smokestacks-act
9. About EIA: Mission and Overview. U.S. Energy Information Administration website. Accessed November 25, 2020. https://www.eia.gov/about/mission_overview.php
10. Electricity Data Browser: Net generation, United States, all sectors, monthly. U.S. Energy Information Administration website. Accessed April 29, 2020. https://www.eia.gov/electricity/data/browser/
11. Layer Information for Interactive State Maps. Energy Information Administration website. Accessed May 8, 2020. https://www.eia.gov/maps/layer_info-m.php
12. Form EIA-860 detailed data with previous form data (EIA-860A/860B). Energy Information Administration website. Accessed December 1, 2020. https://www.eia.gov/electricity/data/eia860/
13. National Emissions Inventory (NEI). United States Environmental Protection Agency website. Published June 2, 2015. Accessed November 23, 2020. https://www.epa.gov/air-emissions-inventories/national-emissions-inventory-nei
14. Air Pollutant Emissions Trends Data. United States Environmental Protection Agency website. Published July 27, 2015. Accessed Nov. 23, 2020. https://www.epa.gov/air-emissions-inventories/air-pollutant-emissions-trends-data
15. The R Project for Statistical Computing. The R Foundation website. https://www.R-project.org/
16. Li Y-R, Gibson JM. Health and air quality benefits of policies to reduce coal-fired power plant emissions: a case study in North Carolina. *Environ Sci Technol.* 2014;48(17):10019–10027. doi: 10.1021/es501358a
17. Kravchenko J, Akushevich I, Abernethy AP, Holman S, Ross WG, Lyerly HK. Long-term dynamics of death rates of emphysema, asthma, and pneumonia and improving air quality. *Int J Chron Obstruct Pulmon Dis.* 2014;9:613–627. doi: 10.2147/COPD.S59995
18. Environmental Health & Engineering, Inc. *Emissions of Hazardous Air Pollutants from Coal-fired Power Plants.* EH&E Report; 2011. https://www.lung.org/getmedia/25962184-d2fc-42f8-b5a3-8ece3257fbab/emissions-of-hazardous-air.pdf.pdf
19. Hoppock D, Adair SK, Murray B, Tarr J. *Benefits of Early State Action in Environmental Regulation of Electric Utilities: North Carolina's Clean Smokestacks Act.* Duke Nicholas Institute for Environmental Policy Solutions; 2012. https://nicholasinstitute.duke.edu/climate/policydesign/benefits-of-early-state-action-in-environmental-regulation-of-electric-utilities
20. Overview of the Cross-State Air Pollution Rule (CSAPR). United States Environmental Protection Agency website. Published February 4, 2016. Accessed November 23, 2020. https://www.epa.gov/csapr/overview-cross-state-air-pollution-rule-csapr
21. Mercury and Air Toxics Standards (MATS). United States Environmental Protection Agency website. Published November 6, 2015. Accessed November 23, 2020. https://www.epa.gov/mats
22. Progress Energy to retire four coal-fired plants by 2017. Power-Eng.com. Published December 1, 2009. Accessed November 23, 2020. https://www.power-eng.com/coal/progress-energy-to-retire-four-coal-fired-plants-by-2017/
23. Kravchenko J, Lyerly HK, Ross W. The health impacts of environmental policy: the North Carolina Clean Smokestacks Act. *N C Med J.* 2018;79(5):329–333. doi: 10.18043/ncm.79.5.329
24. North Carolina Governor Roy Cooper. Executive Order No. 80: North Carolina's Commitment to Address Climate Change and Transition to a Clean Energy Economy. North Carolina Governor's Office; 2018. Published October 29, 2018. https://files.nc.gov/ncdeq/climate-change/EO80--NC-s-Commitment-to-Address-Climate-Change--Transition-to-a-Clean-Energy-Economy.pdf
25. Governor Roy Cooper. Governor Cooper Signs Energy Bill Including Carbon Reduction Goals Into Law. News Release. Office of the Governor; October 13, 2021. Accessed May 4, 2022. https://governor.nc.gov/news/press-releases/2021/10/13/governor-cooper-signs-energy-bill-including-carbon-reduction-goals-law
26. Guidry VT, Thie L, Money EB. Sidebar: health benefits of North Carolina's transition to clean energy. *N C Med J.* 2020;81(5):334–335, Sep. doi: 10.18043/ncm.81.5.334