The public health benefits of a zero-emissions power sector in Virginia

Analysis by the

Virginia Climate Center

Virginia Climate Center

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1 Executive Summary

While the use of nuclear and renewable energy has expanded in recent years, much of Virginia's electricity is still generated using fossil fuels such as oil and natural gas. The consequences of fossil fuel combustion extend beyond global climate change; it also harms people's health and increases health care and health-related costs in Virginia. The analysis presented here finds that a decarbonized power sector will benefit Virginians across the state by reducing our communities' exposure to harmful pollutants, saving lives, reducing lost workdays, and improving the health of Virginia residents.

Assuming a target date of 2045 for complete decarbonization, the health economic benefits to the Commonwealth of Virginia are estimated to range between $141 and $356 million per year, for a cumulative total of $2.8 billion to $7 billion over the next two decades due to avoided adverse health impacts of power sector pollutants. Moreover, these benefits will ramp up throughout the assumed phase-out period, providing Virginia's communities with both immediate benefits and with increasing benefits over time. These health benefits will take many forms. Entirely eliminating power plant emissions of pollution by 2045 will avoid over 600 deaths and more than 200 hospital admissions for respiratory and cardiovascular problems over two decades. Conversely, continuing to emit pollution from Virginia's fossil fuel power plants at the current rate would result in thousands of lost workdays per year, ultimately costing Virginians $387,000 annually or $7.8 million over a 20-year period.

In summary, this analysis shows that completely phasing out of fossil fuel-powered electricity production by 2045, as mandated by current Virginia law and reflected in recent utility projections, will save the lives of Virginians, provide significant economic savings, and reduce the burden of air quality on vulnerable communities and businesses.

The analysis was conducted using EPA's CO-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA). We used the model's 2023 estimates as our demographic and emissions baseline for the analysis and projected a consistent rate of emission reductions between 2023 and 2045 to reach 0% in 2045. Our results reflect ranges from low and high estimates of the effect of pollutants on mortality and health which are pooled from peer-reviewed studies. The scenarios evaluated were based only on reducing fossil fuels used in electric utilities to generate electric power by utilities; they do not account for fossil fuel use in transportation and resource extraction or account for future changes in electricity consumption.

2 Background

Curbing the worst impacts of global climate change will require rapidly transitioning from fossil fuel power generation to clean (i.e., non-polluting) technologies across all sectors of the economy. In the U.S. in 2020, electric power generation accounted for 25% of all carbon emissions (EPA, 2022). In Virginia, the electric power sector emitted 28.8 million metric tons of CO_2 in 2020, accounting for approximately 29% of all carbon emissions within the state (EIA, 2022).

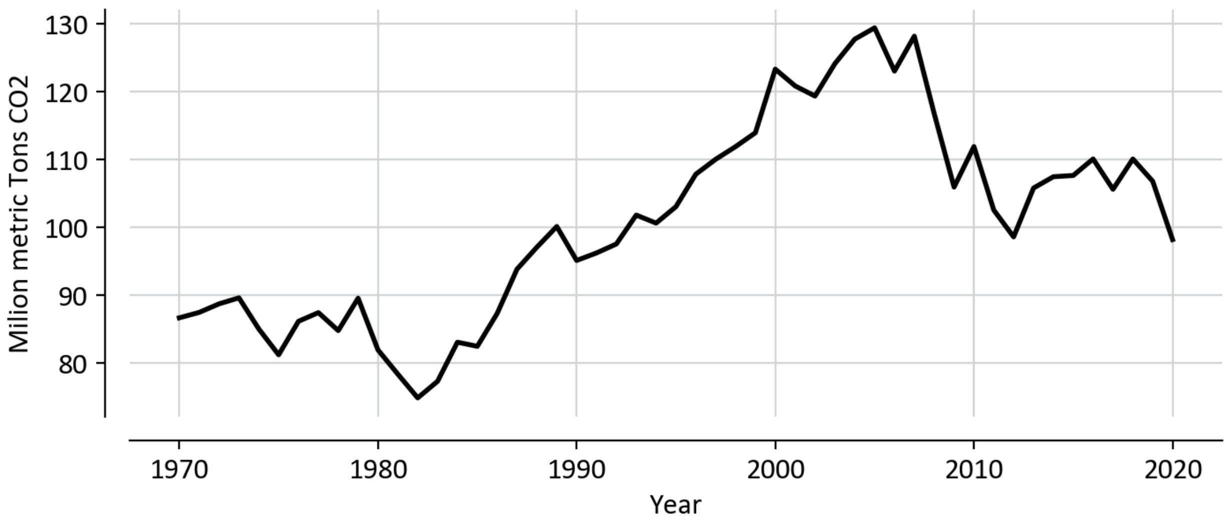

Figure 1. Total carbon emissions in Virginia (1970-2020) across all sectors. Source: Federal Reserve Economic Data (FRED).

There are many benefits associated with a transition to non-fossil fuel fired electric power. In addition to reducing emission of heat-trapping greenhouse gases (GHG), the combustion processes involved in electric generation release other pollutants like particulate matter (e.g., PM2.5 and PM10), sulfur dioxide (SO_2) and nitrous oxides (NO_x) into the air. Studies show that both acute and chronic exposure to these pollutants contributes to cardiovascular, respiratory, and cerebrovascular mortality (Faustini et al., 2014; Hoek et al., 2013; Orellano et al., 2020) across short- and long-term exposures. The shift away from fossil-fuel emissions has already yielded significant benefits for Virginia and the entire Mid-Atlantic region. A study by Millstein et al. (2017) found that increased wind and solar generation in the Mid-Atlantic was responsible for $300 million in savings in 2015 due to avoided health economic costs from air quality.

In our study, we estimate the health and health economic benefits associated with reducing combustion fossil fuel use to produce electric power in Virginia. Proceeding from the assumption that the electricity sector will be fully decarbonized by 2045, as is currently required under state law, we calculated the health and health economic benefits that will accrue statewide, and for each county in Virginia between now and the year 2045.

2.1 Power generation in Virginia

In 2020, Virginia generated close to 82% of its total electric energy consumption, importing the rest from neighboring states. Carbon emissions in the state peaked in the year 2005, when they reached nearly 130 million metric tons of CO_2. Since then, despite a growing demand for electricity, emissions have dropped to 98 million metric tons of CO2, a 20-year low, mostly due to a transition from coal to natural gas as the leading source of electricity generation (Figure 1). Natural gas has become the dominant fuel for electric generation in the state, powering 57% of the total fuel mix and nuclear energy providing 30% (Figure 2). This increase has mostly come due to phasing out of coal power, although there have been minor increases in generation from renewable sources like solar, which now provides approximately 4% of in-state generation. Most generation is concentrated towards the eastern half of the state, with the exception of the large Bath County Hydroelectric plant near the border with West Virginia (Figure 3).

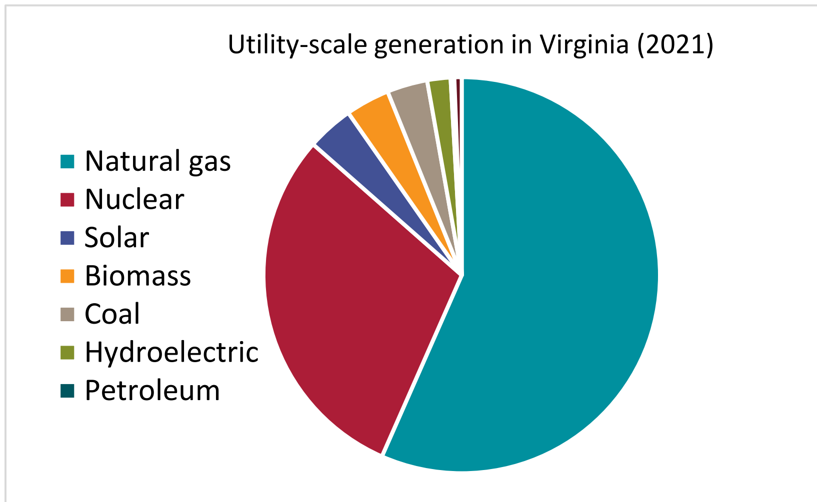

Figure 2. Fuel mix of utility scale generation in Virginia. Source: Energy Information Agency.

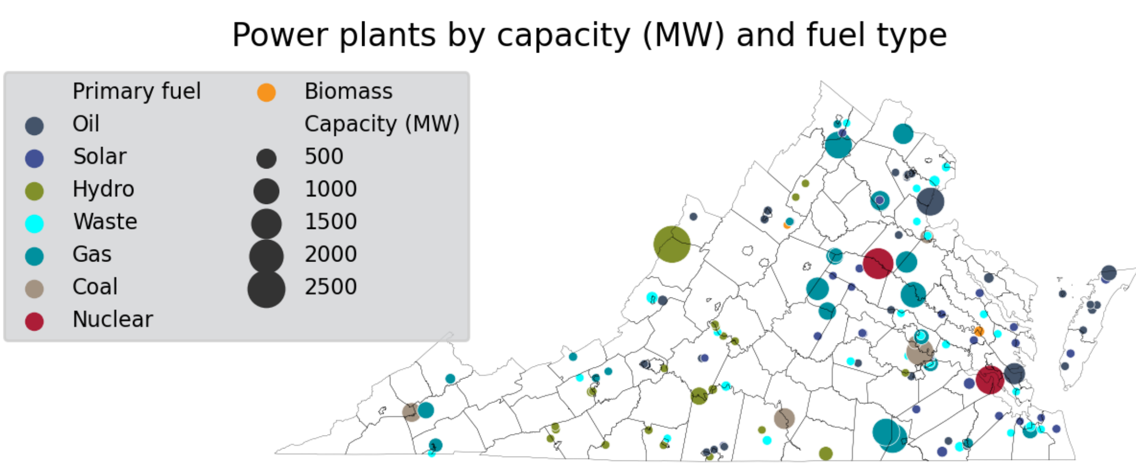

Figure 3. Power plants in Virginia by primary fuel type and installed capacity. Data obtained from the Global Power Plant Database, version 1.3 (World Resources Institute, 2022).

The trend toward decarbonization of electric generation in Virginia is expected to continue. In 2020, the Virginia legislature passed the Virginia Clean Economy Acy (VCEA). The VCEA mandates, among several things, a complete phase-out of fossil fuel electric generation in the state by 2045 (Figure 4); though there are allowances that may push that target to 2050 for some utilities. Planning by utilities in the state has already begun. In 2022, Dominion Energy, one of the largest utilities in Virginia, released a Climate Report (Dominion Energy, 2022) outlining pathways to net-zero carbon emissions across its operations. Their report presents a series of pathways to decarbonization of their electric generation operations following both their current plans to decrease non-fossil fuel power by 2050, as well as a more aggressive pathway consistent with limiting the global temperature increase to 1.5°C. Both pathways propose significant shifts towards wind and solar and a complete phase out of coal at a faster timetable than proposed in the VCEA.

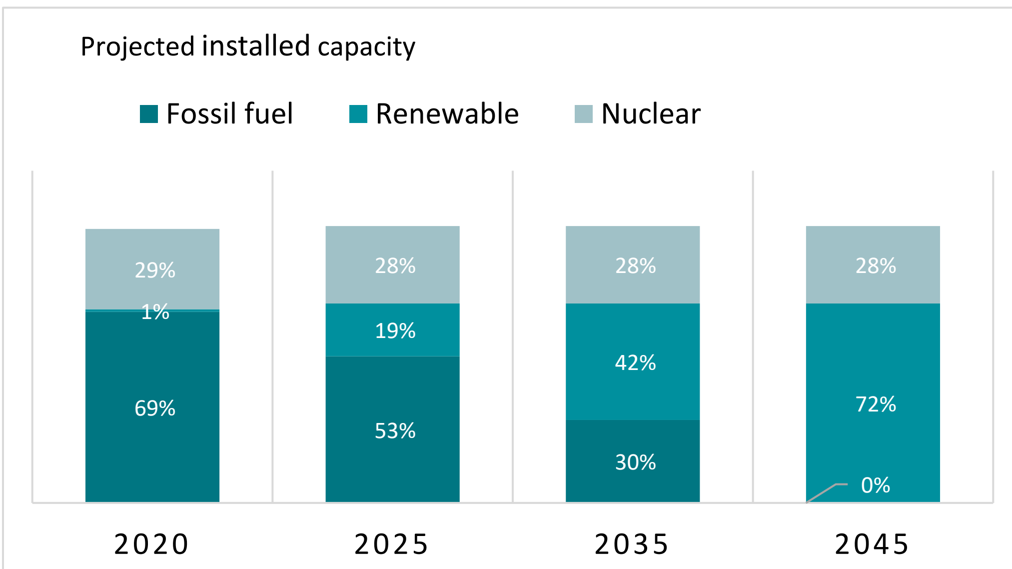

Figure 4. Current decarbonization pathway defined by the Virginia Clean Economy Act of 2020. Source: Virginia Energy Plan (2022).

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2.2 Co-benefits of decarbonization of the electric generation

Compared to coal, combustion of natural gas to generate electricity produces fewer emissions, but this advantage excludes consideration of the problems associated with methane leakage into the atmosphere, and the "lock-in" associated with the long lifespans of natural gas power plants (Hausfather, 2015). Meanwhile, natural gas combustion still produces pollutants, which can harm human health (Burney, 2020). In fact, although natural gas power plants emit reduced amounts of some harmful pollutants like NOx and SO_2, they may emit increased amounts of other pollutants like (VOCs) (Brewer et al., 2016; Pacsi et al., 2013).

In this report, we present an analysis of the health and health cost benefits from transitioning to fossil fuel-free electric generation in Virginia. Our analysis leverages the Environmental Protection Agency's (EPA) COBRA model to investigate, at the county level, the avoided health and health cost impacts of fossil fuel emissions in the state. These impacts include avoided deaths and their related costs, as well as the cost of missed workdays and avoided hospitalizations due to cardiovascular and respiratory illness.

3 Results

Our analysis assumes a study phase-out of fossil-fuel generation as proposed by the VCEA (Figure 4), with a target date for 0% fossil-fuel generation by 2045. We present our findings for what can be expected in 2025, 2030, and 2045. We find considerable health and health economic benefits from decarbonization throughout the time period, with the benefits increasing over time.

3.1 Emissions reductions

Elimination of fossil fuel power from Virginia will prevent the release of large quantities of the harmful pollutant PM 2.5 into our air. The largest reductions will occur throughout the eastern part of the state, coinciding with the largest concentrations of fossil fuel plants (Figure 5). The largest reductions in PM 2.5 will be in highly populated areas like Fairfax County and the Richmond metropolitan area reaching up to 0.29 μg/m^3. The remaining ambient PM 2.5 in 2045 will come from sources like transportation, industry, and out-of-state fossil-fuel generation – unless those sources of pollution are also reduced.

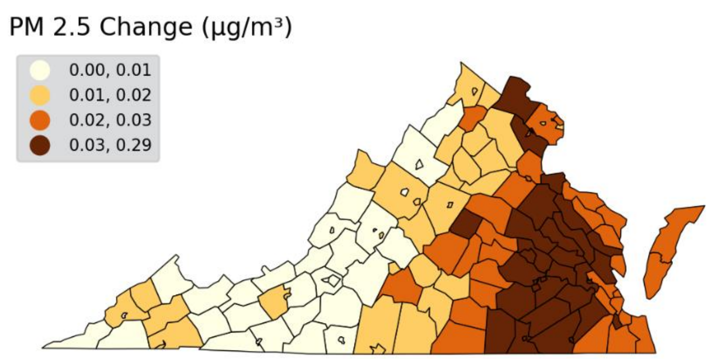

Figure 5. Ambient PM2.5 reduction (in μg/m3) per year from 100% fossil-fuel free power generation.

The COBRA model uses these reductions to calculate avoided health impacts, which are based on reported dose-response relationships between PM 2.5 and various health impacts. In turn, these reductions in health harms are monetized according to estimated costs of health services (e.g., hospitalizations), work loss, and the standard value of statistical life.

3.2 Health benefits

Reducing emissions from fossil-fuel power plants can save human lives. Benefits will ramp up throughout the assumed phase-out period, providing both immediate and long-term benefits to Virginia’s communities. By 2025, if emissions from electricity production have been reduced by 13.9%, the annual number of avoided deaths is projected to be between 2.0 and 4.4. By 2045, if emissions have been reduced by 100%, the annual number of avoided deaths is projected to be between 14 and 32 (Figure 6). Although the range between the high and low estimate increases as the amount of fossil fuel decreases, even the lowest avoided mortality estimate in 2045 is larger than the high-end estimate for 2035.

At the county-level, avoided mortality is mostly distributed throughout the eastern part of Virginia (Figure 7). When normalized by total county population, these counties coincide with the highest concentration of fossil fuel power plants. This includes the county with the largest remaining coal plant in Virginia, Chesterfield County, which can expect to avoid between 15 and 36 deaths per decade after 100% phase-out of fossil fuels. When normalized by county population, the impacts on less populous regions becomes more apparent. The top examples include Emporia and Brunswick counties, which could avoid 26-59 and 20-45 deaths per 100,000 residents, respectively.

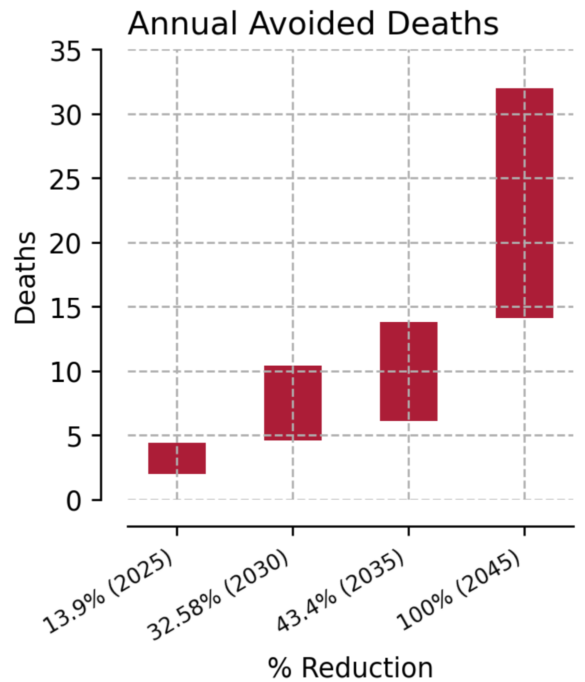

Figure 6. Total yearly avoided deaths by percent reduction in electric generation from fossil fuels. The bars show the low and high estimates in outcomes by percent reduction in fossil-fueled emissions.

The health benefits of fossil fuel phase-out are not limited to avoided deaths from respiratory and cardiovascular disease. Costs of hospitalization admissions due to exposure to PM 2.5 are highest in the eastern side of the state, reaching approximately $39,000 per 100,000 people in the highest quintile (Figure 8). Exposure to pollutants also impact workers and the workforce. For example, studies have shown that exposure to air pollution, namely PM 2.5 and ozone, impact the incidence of work loss days. COBRA uses a statistical model that links ambient pollution changes to work loss days (Ostro, 1987). Results show the majority of work loss days occur in highly populated counties along the I-95 highway, which runs North-South in the eastern part of the state and also coincide with a large amount of installed generation capacity. Values of work loss days in the top quintile start at 10.65 and can go as high as 224.3 work loss days per 100 people per year (Figure 9). We note that results for work loss days only

Figure 7. Low (left) and high (right) estimates of annual avoided deaths per 100,000 people by county.

include the population aged 18-64, which were part of the Ostro 1987 study. The share of the workforce age 65 and older has increased and is projected to keep increasing as total population grows older, having reached close to 16% in 2010 (US Bureau of Labor Statistics). However, although older adults have higher risks of being impacted by air pollutants, there are no dose-response studies linking work loss days in that population.

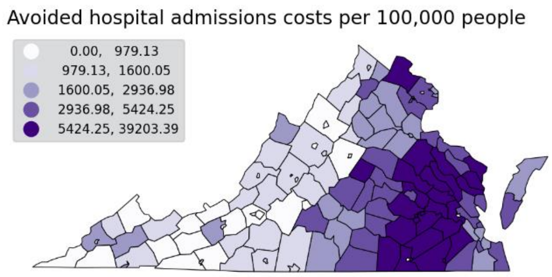

Figure 9. Estimated annual avoided cost of hospitalizations (respiratory and cardiovascular causes) due to PM 2.5 exposure.

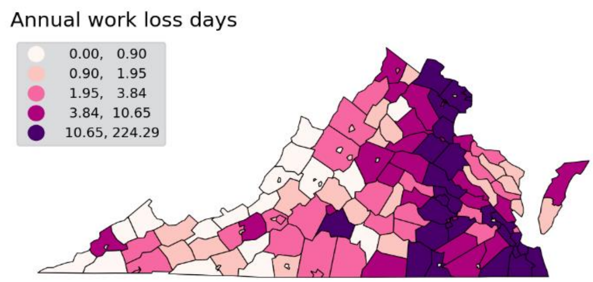

Figure 8. Estimated annual avoided work loss days per 100 people by county.

We also present monetized benefits of the overall health costs of reaching 0% fossil fuel generation. Our analysis using the COBRA tool includes a range of health benefits from avoided emissions. These impacts include work loss days and mortality related benefits, as well as those related to reduced incidence in respiratory and cardiovascular disease-linked hospitalizations. Avoided premature mortality is monetized using the *value of statistical lives* (VSL) approach. Our results use a VSL value of $9.7 million derived from a 26-study mean, as employed by COBRA. Our results also reflect the use of both a 3% and 7% discount rate, which quantifies the preference of individuals in receiving benefits in the present versus at a later date. Our high estimates use the high estimate monetized benefit with the low 3% discount rate, with the low estimate using the 7% value.

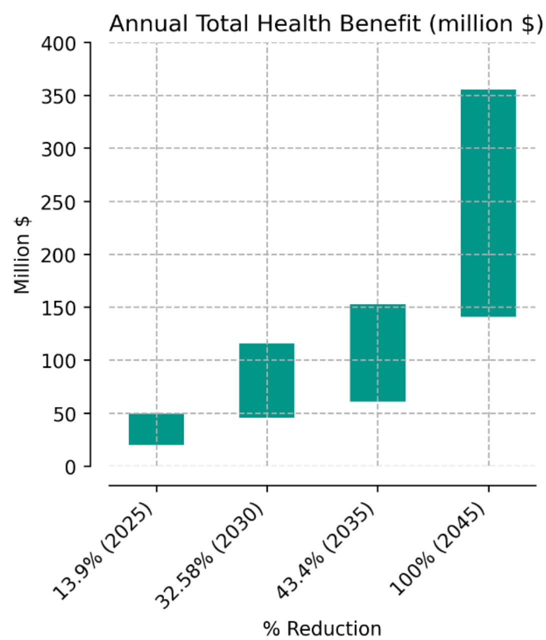

Figure 10. Total yearly economic benefit from avoided health costs and mortality. The bars show the low and high estimates in outcomes by % reduction in fossil-fueled emissions.

Results show that economic benefits of avoided health impacts begin to accrue at modest levels of fossil fuel phase-out. At 13.9% reduction, estimated total benefits range between 19.6 and 49.4 million dollars per year (Figure 10). With fully non-fossil fuel generation, total avoided health cost lies between $140 and 355 million annually. The increase in benefits mirrors results from mortality data, as the economic benefit of avoided mortality is the strongest driver of total economic benefits. This result is also reflected at the county level, where a combination of proximity to fossil fuel power plants and population places the highest economic benefits in counties along the I-95 corridor. These include highly populated counties like Fairfax and Prince William in Northern Virginia, as well as Henrico County in the Richmond metropolitan area.

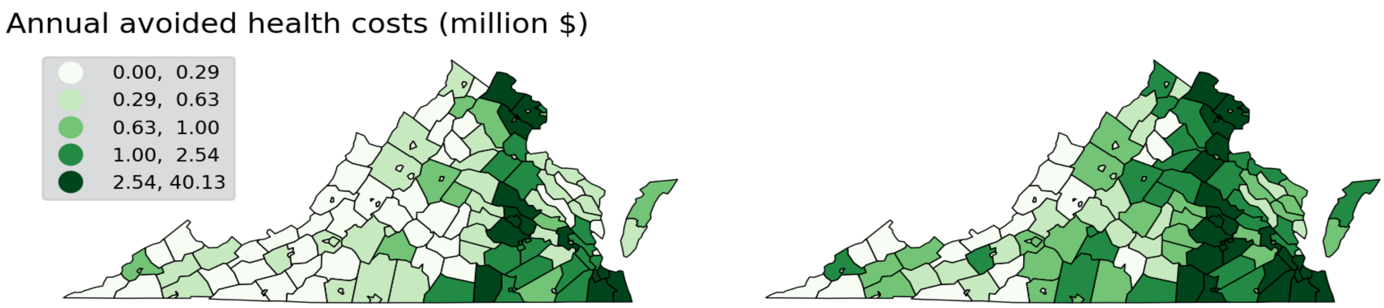

Figure 11. Low (left) and high (right) estimates of annual avoided health costs (million $).

Full decarbonization can also help reduce existing injustices related to pollutant exposure. We employ the Center for Disease Control's (CDC) Social Vulnerability Index (SOVI) data (Flanagan et al., 2011). Specifically, we use the SOVI dataset's estimate of the share of the population in each county with income below 150% of the poverty line (EP_POV150), based on household income estimates from the 2016-2020 American Community Survey (ACS).

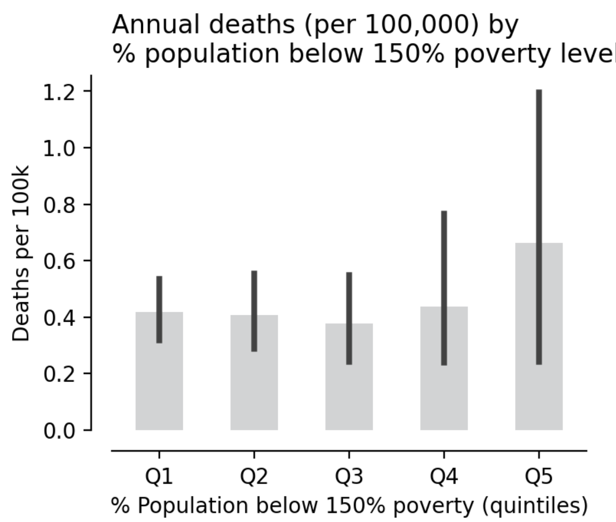

Figure 12. Avoided deaths due to power plant emissions by share of the population living below 150% the poverty level for each county.

We find that the benefits of avoided mortality are highest for those counties in the top quintile of EP_POV150. The value of EP_POV150 for these locations ranges between 30 and 50% of their total population. Mean annual avoided deaths across counties per 100,000 people in the bottom four quintiles were somewhat constant at a value of approximately 0.4, although the maximum value in the fourth quintile (Q4) reached up to 3.66. Meanwhile, annual avoided deaths per 100,000 people in counties at the top quintile (Q5) was 0.66 on average, with a maximum value of 5.9. On average, this represents an increase of 50% in counties with most people living significantly below poverty across Virginia.

In summary, our analysis shows that completely phasing out of fossil fuel powered electricity production by 2045, as current plans aim and reflected in recent utility projections, will save the lives of Virginians, provide significant economic savings, and reduce the burden of air quality on vulnerable communities and businesses. Results from simulations show that these benefits increase with decreases in fossil fuel emitting power, with saved lives and reduced costs as early as 2025 under current plans. Finally, the results show that the benefits of a fossil fuel phase-out in the electric power sector will most benefit communities with a significant share of people living below poverty.

4 Methods

4.1 COBRA and Setup

The analysis was completed by using the EPA's CO-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA). COBRA links a combination of models to estimate impacts of modifying emissions on ambient pollution and health. To accomplish this, it uses extensive data on U.S. populations and fossil fuel emissions, as well as projections of these factors for years in the near future. The model estimates economic and health benefits based on fossil fuel emissions modifications, which are then converted into approximate changes in ambient PM2.5 concentrations that are used to project these estimates (US EPA, 2017). The results depend on a few different inputs, those being baseline year, selected locations, emissions modifications, and selected discount rate. Based on all the inputs, COBRA will run the scenario on the scale of the entire U.S. and then provide the calculated benefits for each individual U.S county.

COBRA includes baseline data for the years 2016, 2023, & 2028, all of which include baseline emissions, populations for all U.S. counties, and functions for the health effects. The 2016 baseline year includes actual historical data, whereas 2023 and 2028 show projections based on current emissions and population trends.

4.2 Scenarios

When creating an emissions scenario, the first step is to select the locations of interest. Scenarios can be run on the scale of the entire U.S., or only for specific states. COBRA also allows for a further downscaling to the county level where scenarios can be created for specific counties. For this project, the baseline year of 2023 was used for the scenarios to show projections from now to 2045, with each scenario being run on a 3% and 7% discount rate separately.

The second step in creating a scenario is to select the necessary emissions tiers. The emissions are organized in three different tiers, with tier 1 encapsulating the processes that created the emissions, such as fuel combustion, metal processing, and highway vehicles. Tier 2 represents the fossil fuel type burned, or a subcategory of the tier 1 process. Tier 3 is mainly used to define a specific fossil fuel, such as bituminous or subbituminous for coal. For these scenarios, "fuel combustion: electric utility" was selected for tier 1, with all tiers (2 & 3 included) under this process (coal, oil, natural gas, other, internal combustion) being used for the scenarios.

The last step of creating a scenario is to make the desired modifications to each emission. COBRA allows for either the reduction or increase of all listed emissions, those being PM 2.5, SO_2, NOx, VOCs, and NH_3. The emissions can be modified by percentages or tons, with the maximum reduction being the total baseline emission value for each individual emission. The scenario used a percentage reduction of 100% for all emissions.

Before running the scenario, COBRA requires the selection of a discount rate with which the model will run the scenario on. COBRA includes two discount rates: 3% and 7%. These discount rates represent the monetary loss (opportunity cost) from the investments made on the selected emissions reductions in each scenario. For the 3% discount rate, this represents an interest rate calculated based on government funding, and the 7% discount rate assumes a monetary loss based on private investments. The 7% discount rate results in lower total health benefits, but also displays more immediate health benefits than the 3% discount rate. Both the 3% and 7% discount rate were implemented here to show the difference in estimations between the two rates.

4.3 Reported Quantities

After running a scenario, COBRA outputs a table of the results that can be exported to a .csv file or Excel spreadsheet. Within the table, the rows are used to organize all U.S. counties, with the columns displaying each specific health benefit. The categories of health benefits included in this report are high and low estimates for health costs, avoided mortality, and prevented work loss days (EPA, 2021). The benefits for each county are only based on the selected locations and emissions modifications, meaning counties located far from the selected region will likely show low benefits.

For each analysis year, COBRA outputs yearly totals of health benefits and its monetized amount. However, for mortality, the underlying model assumes that deaths avoided do not occur instantly, but over a period of time. The model uses a 20-year time horizon to estimate the avoided costs of mortality due to reduced emissions.

4.4 Limitations

Our analysis uses COBRA to show the benefits of phasing out fossil fuels in the electric generation sector in Virginia. Limitations inherent to COBRA and simulation choices may increase uncertainty in interpretation of results.

The scenarios simulated here do not include externalities of electric generation and only account for direct emissions from power plants. One potentially large source of emissions may be due to transportation and sourcing of fossil fuels from sources to each power plant. A review by Steinmann et al (2014) showed that these upstream emissions range between 5-9% of coal-fired power's life cycle, although values vary significantly depending on fuel origin and method of extraction.

Our analysis also does not prescribe any changes in emissions from sources outside the state of Virginia. This may add uncertainty to future emissions, particularly in counties close to state borders. Finally, uncertainties are introduced in the formulation of dose-response functions based on previous studies. To somewhat mitigate this limitation, we present, where available, low and high estimates of potential impacts in our simulation scenarios as a representation of a plausible range of benefits.

5 About the Virginia Climate Center

The Virginia Climate Center (VCC) at George Mason University is a multidisciplinary research center providing climate extension services to all communities in the Commonwealth of Virginia. The VCC brings together scientists from a broad range of disciplines including climate science, engineering and public health. The VCC's mission is to engage with Virginia's municipal officials, businesses, and other community leaders as well as co-develop information and tools that will inform municipal decisions, enhance Virginia's resiliency, save tax dollars, and improve the productivity and profitability of Virginia's businesses.

Contributors

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6 References

Brewer, E., Li, Y., Finken, B., Quartucy, G., Muzio, L., Baez, A., Garibay, M., & Jung, H. S. (2016). PM2.5 and ultrafine particulate matter emissions from natural gas-fired turbine for power generation. *Atmospheric Environment*, *131*, 141–149. https://doi.org/10.1016/j.atmosenv.2015.11.048

Burney, J. A. (2020). The downstream air pollution impacts of the transition from coal to natural gas in the United States. *Nature Sustainability*, *3*(2), Article 2. https://doi.org/10.1038/s41893-019-0453-5

Dominion Energy. (2022). *Climate Report 2022*. https://www.dominionenergy.com/-/media/pdfs/global/company/esg/2022-climate-report.pdf

EIA. (2022). *Introduction and Key Concepts: State Energy-Related Carbon Dioxide Emissions Tables*. Energy Information Agencty. https://www.eia.gov/environment/emissions/state/pdf/intro_key_concepts.pdf

EPA. (2022). *Inventory of U.S. Greenhouse Gas Emissions and Sinks (1990-2020)* (EPA 430-R-22-003). U.S. Environmental Protection Agency. https://www.epa.gov/ghgemissions/draft-inventory-us-greenhouse-gas-emissions-and-sinks-1990-2020

Faustini, A., Rapp, R., & Forastiere, F. (2014). Nitrogen dioxide and mortality: Review and meta-analysis of long-term studies. *European Respiratory Journal*, *44*(3), 744–753. https://doi.org/10.1183/09031936.00114713

Flanagan, B. E., Gregory, E. W., Hallisey, E. J., Heitgerd, J. L., & Lewis, B. (2011). A Social Vulnerability Index for Disaster Management. *Journal of Homeland Security and Emergency Management*, *8*(1). https://doi.org/10.2202/1547-7355.1792

Hausfather, Z. (2015). Bounding the climate viability of natural gas as a bridge fuel to displace coal. *Energy Policy*, *86*, 286–294. https://doi.org/10.1016/j.enpol.2015.07.012

Hoek, G., Krishnan, R. M., Beelen, R., Peters, A., Ostro, B., Brunekreef, B., & Kaufman, J. D. (2013). Long-term air pollution exposure and cardio- respiratory mortality: A review. *Environmental Health*, *12*(1), 43. https://doi.org/10.1186/1476-069X-12-43

Millstein, D., Wiser, R., Bolinger, M., & Barbose, G. (2017). The climate and air-quality benefits of wind and solar power in the United States. *Nature Energy*, *2*(9), Article 9. https://doi.org/10.1038/nenergy.2017.134

Orellano, P., Reynoso, J., Quaranta, N., Bardach, A., & Ciapponi, A. (2020). Short-term exposure to particulate matter (PM10 and PM2.5), nitrogen dioxide (NO2), and ozone (O3) and all-cause and cause-specific mortality: Systematic review and meta-analysis. *Environment International*, *142*, 105876. https://doi.org/10.1016/j.envint.2020.105876

Ostro, B. D. (1987). Air pollution and morbidity revisited: A specification test. *Journal of Environmental Economics and Management*, *14*(1), 87–98.

Pacsi, A. P., Alhajeri, N. S., Zavala-Araiza, D., Webster, M. D., & Allen, D. T. (2013). Regional Air Quality Impacts of Increased Natural Gas Production and Use in Texas. *Environmental Science & Technology*, *47*(7), 3521–3527. https://doi.org/10.1021/es3044714

Steinmann, Z. J. N., Hauck, M., Karuppiah, R., Laurenzi, I. J., & Huijbregts, M. A. J. (2014). A methodology for separating uncertainty and variability in the life cycle greenhouse gas emissions of coal-fueled power generation in the USA. *The International Journal of Life Cycle Assessment*, *19*(5), 1146–1155. https://doi.org/10.1007/s11367-014-0717-2

US EPA, O. (2017, June 26). *User's Manual for the CO - Benefits Risk Assessment (COBRA) Screening Model* [Data and Tools]. https://www.epa.gov/cobra/users-manual-co-benefits-risk-assessment-cobra-screening-model