The impact of coal-burning power plants and coal ash impoundments on health of residential communities

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Mortality increases with outdoor air pollution
Levels of PM$_{2.5}$ and ozone related to overall death rates

Notes: - Units of mortality attributed to air pollution (PM$_{2.5}$ and O$_3$), deaths per area of 100km x 100km (color coded), 2010. White= annual mean PM$_{2.5}$ and O$_3$ below the concentration–response thresholds where no excess mortality is expected.

Source: Lelieveld et al; NATURE, 2015
Sources of air pollution linked to increased mortality

In NC, a predominante source is power generation.

- IND, industry
- TRA, land traffic
- RCO, residential and commercial energy use (e.g., heating, cooking)
- BB, biomass burning
- PG, power generation
- AGR, agriculture
- NAT, natural sources.

Note: In the white areas, annual mean PM$_{2.5}$ is below the concentration–response threshold.

Source: Lelieveld et al.; NATURE, 2015
Coal-fired power plants: interactions with the environment

Source: the U.S. EPA
https://www.epa.gov/eg/steam-electric-power-generating-effluent-guidelines-2015-final-rule
Health and coal-fired power plant

Source: Munawer, 2018
Fly ash and health issues

- **Fly ash** is a coal combustion product composed of fine particles of burned fuel that are driven out of coal-fired boilers together with the flue gases.

- PM10, PM10-2.5, and PM2.5: could escape emission control devices and upon inhalation penetrate deep into respiratory tract and deposit in lungs.

- PMs of fly ash could be enriched up to 10 times in metals compared to bulk ash *(US EPA, 2009)*.

- Inorganic nanoparticles are extremely small and can accumulate even deeper in respiratory tissue *(Silva, Boit, 2011)*.

Source: https://www.arthamins.com/fly-ash.htm
Distance from the coal-burning power plant and the size of at-risk populations

- Populations living in close proximity to coal power plants are usually small. However, the effects on health could be observed in much larger populations living relatively far from the power plant.

- Fly ash particles can be transported in the atmosphere up to 30 km from the power station (Iordanidis et al, 2008; Jones et al, 2002).

- Study on the use of the Best Available Control Technology (BACT) on 2 coal-fired power plants in Massachusetts: the max benefit occurs within 25-40 km from the power plant where less than 10% of the population lives. However, the benefits could be also obtained for much larger population living as far as 100 km from the source (Levy, Spengler, 2002).
Coal ash impoundments (slurry ponds and landfills): to dewater the fly ash (which is stored in wet form in ash dredge cells).

- Often located in close proximity to residential communities, often of low-income communities (Zierold, Sears, 2015).
- Contain polycyclic aromatic hydrocarbons (PAHs), spectrum of metals (arsenic, mercury, lead, cadmium, vanadium, chromium, nickel, zinc, etc.)

Source: Harkness, Sulkin, Vengosh, 2016
### Potential health effects for metals related to coal power plants emission

<table>
<thead>
<tr>
<th>Metal</th>
<th>Conditions/diseases correlated with exposure</th>
<th>Information on particular aspects of exposure</th>
<th>Recognition by official agencies as a hazardous substance for humans</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead</td>
<td>Abdominal pain, memory loss, damage of developing nervous system in fetus, miscarriages, and intellectual disabilities in children [A47].</td>
<td>There is no known level of lead exposure that is considered safe. The neurological effects of lead are believed to be irreversible.</td>
<td>The World Health Organization (WHO) has recognized lead as one of 10 chemicals of major public health concern [A48]. Classified as the coal ash component that constitutes a major environmental health problem [A49].</td>
</tr>
<tr>
<td>Mercury</td>
<td>Exposure of pregnant women can cause lower intelligence levels, delayed neurodevelopment, and changes in vision and memory in the offspring [A50]. Affects fetus development with toxic effects on central and peripheral nervous system (including cognitive and motor dysfunction), gastrointestinal and immune systems, as well as on lung, kidneys (may cause kidney failure), skin, and eyes [A51].</td>
<td>Emitted into the atmosphere from coal-burning power plants and deposited into waterways, converted to methylmercury, and passed up the aquatic food chain [A51, A52]. Humans ingest mercury with consumption of methylmercury contaminated fish [A50].</td>
<td>The WHO considered it one of the top 10 chemicals of major public health concern [A50].</td>
</tr>
<tr>
<td>Vanadium</td>
<td>Occupational exposure is associated with tremor, nausea, transient coronary insufficiency, cardiac arrhythmias, anemia, leukopenia, and lung inflammation (the latter is reported for high-dose exposures) [A53]. Modest dose-related increase in inflammation in lung and cardiovascular symptoms (arrhythmia) [A53, A54]. May augment lung carcinogenesis in susceptible individuals through oxidative stress-mediated pathways [A55]. Data on the effects of low-dose vanadium exposure on hematopoiesis are inconsistent [A56].</td>
<td>Excessive intake of vanadium has been recognized as potentially dangerous for human health [A57].</td>
<td>The International Agency for Research on Cancer (IARC) has determined that vanadium is possibly carcinogenic to humans [A58].</td>
</tr>
<tr>
<td>Cobalt</td>
<td>Impact on cardiovascular and respiratory systems following cobalt exposure near or even slightly under the current occupational exposure limit [A59]. Associated with hemotological and endocrine dysfunctions [A60].</td>
<td>It is an essential trace element but is toxic in higher concentrations [A61].</td>
<td>IARC has reported carcinogenic potential and reproductive toxicity of cobalt [A62].</td>
</tr>
</tbody>
</table>

Lead, mercury, vanadium, cobalt: potential impact on
- nervous system,
- fetus development,
- increased risk of kidney failure,
- anemia,
- cardiac arrhythmia,
- immune system, etc.
Hexavalent chromium, arsenic, silica, cadmium: potential impact on

- respiratory system,
- circulatory system,
- developmental effects,
- neurotoxicity,
- increased risk of kidney disease,
- diabetes,
- impaired liver function,
- lung cancer,
- cancer of urinary bladder,
- complications of pregnancy,
- Alzheimer’s disease, etc.

<table>
<thead>
<tr>
<th>Hexavalent chromium</th>
<th>Arsenic</th>
<th>Quartz and crystalline silica</th>
<th>Cadmium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can damage the upper respiratory tract [A57].</td>
<td>Long-term exposure can increase the risk of cancers of bladder and lung, skin damage (pigmentation changes and hyperkeratosis), developmental effects, cardiovascular disease, neurotoxicity, diabetes, and liver damage [A57, A65].</td>
<td>Higher concentrations of coal-derived components of ash of ultratine size quartz and nanoparticles (&lt;50 nm) of crystalline silica correlated with increased risk of lung cancer [A70].</td>
<td>Is associated with increased lung cancer risk [A65, 1]. Affects digestive and respiratory systems, skin, kidney, and skeletal system (osteoporosis) [A73, A74].</td>
</tr>
<tr>
<td>Reported toxic effects for chronic exposure to chromium include dermatitis, bronchopulmonary disorders, kidney disease, liver damage, diseases of the circulatory system, lung cancer, and complications of pregnancy and labor [A63].</td>
<td>The evidence on carcinogenic effect is compelling for both the inhalation and ingestion routes of exposure. There is evidence of dose-response relationships within exposed populations for both types of exposure [A68].</td>
<td>The IARC Working Group noted that “carcinogenicity may be dependent on inherent characteristics of the crystalline silica or on external factors affecting its biological activity or distribution of its polymorphs [A71].”</td>
<td>Cadmium exposure at an early age should be limited as much as possible to prevent direct effects on children and to prevent accumulation, which may have serious health effects manifesting at older ages [A75].</td>
</tr>
<tr>
<td>Chromium in its hexavalent oxidation state is widely recognized as potentially carcinogenic and highly soluble [A64], whereas trivalent Cr (III) is less soluble and of much less concern to human health.</td>
<td>The evidence on carcinogenic effect is compelling for both the inhalation and ingestion routes of exposure. There is evidence of dose-response relationships within exposed populations for both types of exposure [A68].</td>
<td>The IARC Working Group noted that “carcinogenicity may be dependent on inherent characteristics of the crystalline silica or on external factors affecting its biological activity or distribution of its polymorphs [A71].”</td>
<td>Cadmium exposure at an early age should be limited as much as possible to prevent direct effects on children and to prevent accumulation, which may have serious health effects manifesting at older ages [A75].</td>
</tr>
<tr>
<td>IARC has classified chromium (IV) in Group 1 (carcinogenic to humans) [32, A63].</td>
<td>Carcinogen recognized by IARC [A65, A66, A69]</td>
<td>IARC reclassified quartz and crystalline silica from a class 2 to a class 1 carcinogen based on sufficient evidence of its carcinogenicity in both humans and experimental animals [13].</td>
<td>Cadmium is recognized as a toxic metal that constitutes a major environmental health concern [A49].</td>
</tr>
</tbody>
</table>

Note: A detailed discussion on radioactive components in coal ash is presented in the text.
Radioactive contaminants

• Radium, thorium, and uranium are the main sources of low-dose IR exposure in coal ash.

• Radioactive elements can accumulate in lungs, gradually enter blood circulation, and deposit in bones and teeth to remain for life.
Studies on health impacts of coal-burning power plants

- Research on the health effects of exposures related to coal-burning power plants in humans is limited.
- Most of the studies of the health impact of coal ash are based on animal models or in vitro experiments.
- No studies with direct measurements of exposure and health outcomes are currently available for the communities adjacent to landfills or coal ash impoundments in the US.

<table>
<thead>
<tr>
<th>Region</th>
<th>Total PM$_{2.5}$ emissions (kilotons)</th>
<th>Predicted average YLL per capita (GAINS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>European Union (EU-27)</td>
<td>1,000</td>
<td>0.5</td>
</tr>
<tr>
<td>India</td>
<td>7,000</td>
<td>2.5</td>
</tr>
<tr>
<td>China</td>
<td>10,000</td>
<td>3.5</td>
</tr>
</tbody>
</table>

- Overall life expectancy: coal-fired sources of energy are predicted to causes a 0.5-year decrease in LE in European countries and up to a 3.5-year decrease in developing countries (Gohlke et al, 2011).
All-cause mortality:

- 10 µg/m³ increase in annual level of PM2.5 is associated with up to 14% increase in mortality;
- If 29 proposed plants in Virginia were operational, that will result in 104 cumulative excess deaths over a 6-year period;
- Emissions of 7 power plants in Georgia result in 500 estimated deaths/year;
- Applying BACT (Best Available control Technology) standards to 2 Massachusetts power plants would lead to 70 fewer premature deaths/year.
- Emissions from 9 Illinois power plants were associated with 320 premature deaths/year;
- Declines in SO2 and PM2.5 emissions in North Carolina since passage of the Clean Smokestacks Act resulted in estimated 1700 deaths prevented in 2012.
## Disease-specific outcomes:

- **Lung cancer**: increased mortality with increase of PM2.5;
- **Emphysema**: decline of mortality with SO2 decline;
- **Asthma**: decline of mortality with lower SO2 and PM10 levels;
- 60 fewer CVD hospital admissions and 160 fewer pediatric asthma ED visits per year due to PM2.5 reduction (Washington, DC);
- **CVD**: risk of death increases with PM2.5 level;
- **Ischemic heart disease, arrhythmia, heart failure, cardiac arrest**: increased mortality with increasing PM level;
- **Diabetes**: increased risk of diabetes progression/complications with increasing levels of SO2 and PM2.5.
Infant health:

- **Low birth weight**: risk increases with increasing PM$_{10}$ level (Nevada study);
- **Infant mortality**: respiratory causes of mortality increase with increasing PM$_{10}$ level (across-the-US study).

<table>
<thead>
<tr>
<th>Disease or mortality cause</th>
<th>Effects of air pollutants known to be associated with coal-burning power plant emissions: studies on long-term exposure</th>
<th>Studies of impacts of coal-burning power plant emission or study on other measurements related to coal-burning power plants</th>
<th>Area: US, US state, Europe</th>
<th>Authors, year of publication, reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low birth weight</td>
<td>In multiple linear regression analysis, exposure to 10-µg/m$^3$ increase in PM$<em>{10}$ level in the 3rd trimester of pregnancy can be associated with a birth weight reduction of 11 g (95% CI = 2.3-19.8 g). PM$</em>{10}$ was not found to be associated with the risk of low birth weight in logistic regression analysis.</td>
<td>Nevada</td>
<td>Chen et al, 2002 [64]</td>
<td></td>
</tr>
<tr>
<td>Infant mortality</td>
<td>Adjusted odds ratio (OR) of 1.16 (95%CI = 1.06-1.27) was obtained for a 10-µg/m$^3$ increase in PM$_{10}$ level for respiratory causes of infant mortality.</td>
<td>Across the US</td>
<td>Woodruff et al, 2008 [65]</td>
<td></td>
</tr>
</tbody>
</table>
Children health

- Elevated levels of inflammatory cytokines in child’s brain are associated with increased risk of diseases of CNS (Block et al, 2009).

- Children from communities located near coal-fired power plants had more frequent emotional, behavioral, and learning disorders than children living far from these plants (Zierold, Sears, 2015).

- Study in Texas: for every 10 miles from power plant there was an associated decrease in autism incident risk of 1.4% (Palmer et al., 2009).

- Children are more vulnerable to exposures to emissions:
  - prolonged time of outdoor activities,
  - greater air consumption relative to lung mass and body weight,
  - frequent mouth breathing (less filtering through nasal passages) (Goldizen et al, 2016).
Risk of cognitive dysfunction and neurodegeneration in adults

Neurodegeneration and Alzheimer’s disease risk:

- The principal components of coal fly ash (e.g., aluminosilicates and magnetite) are found in the abnormal protein material that characterizes Alzheimer’s disease (Whiteside et al., 2018).

- Aluminum (Rondeau et al., 2009; Walton, 2011)
- Arsenic (Gong et al., 2010; Gharibzadeh et al., 2008)
- PM2.5 (Calderon-Garciduenas et al., 2013; Moulton et al, 2012)
- Iron, silicates (Collingwood et al., 2008; Castellani et al, 2007)
- Mercury (Farina et al., 2013)
Do we have some good news here in North Carolina?
Improving air quality in North Carolina

• **The Clean Air Act** of 1970 established strict standards for reducing air pollution from new fossil-fueled electric power plants and other stationary sources.

• In 2002, North Carolina enacted the **Clean Smokestacks Act** to set the caps on total annual emissions of NO$_x$ and SO$_2$ by Duke Energy and Progress Energy.
Air pollutants levels in the areas surrounding active or retired coal power plants in North Carolina, 1998-2013

Average emissions in active (red) and retired (blue) coal power plants in NC.
Reduction of air pollutants levels in North Carolina

Note: Individual pollutants were placed onto a single graph by utilizing arbitrary units to enable a collective visualization of the trends.

Source: Kravchenko et. al. 2014
Decrease of death rates (in %) of asthma and emphysema in North Carolina per decrease of air pollutant level by 10 units of measurement (10 ppb or 10 µg/m³), 1992-2010. Age 65+, adjusted for smoking prevalence and seasonal deaths fluctuations.

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Asthma</th>
<th>Emphysema</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO₂</td>
<td>-10.4%#</td>
<td>-4.8%#</td>
</tr>
<tr>
<td>NO₂</td>
<td>-33.1%*</td>
<td>-15.0%*</td>
</tr>
<tr>
<td>PM₁₀</td>
<td>-25.8%#</td>
<td>n/s</td>
</tr>
<tr>
<td>PM₂.₅</td>
<td>n/s</td>
<td>-13.5%*</td>
</tr>
</tbody>
</table>

Notes:
- *p<0.05;
- #significant under Bonferroni correction;
- n/s - p>0.05.

Source: Kravchenko, Lyerly, 2015
Decrease of death rates (in %) of cardiovascular diseases in North Carolina per decrease of air pollutant level by 10 units of measurement (10 ppb or 10 µg/m³), 1992-2010. Age 65+, adjusted for smoking prevalence and seasonal deaths fluctuations.

### Pollutant Changes

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Myocardial infarction (MI)</th>
<th>Heart failure (HF)</th>
<th>Cerebrovascular disease</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO₂</td>
<td>-5.5%#</td>
<td>-2.0%#</td>
<td>-4.7%#</td>
</tr>
<tr>
<td>NO₂</td>
<td>-14.7%*</td>
<td>-5.7%*</td>
<td>-15.3%#</td>
</tr>
<tr>
<td>PM₁₀</td>
<td>-12.0%#</td>
<td>n/s</td>
<td>-6.8%#</td>
</tr>
<tr>
<td>PM₂.₅</td>
<td>-11.0%*</td>
<td>-10.5%#</td>
<td>-11.7%#</td>
</tr>
</tbody>
</table>

**Notes:**
- *p<0.05;
- #significant under Bonferroni correction;
- n/s - p>0.05.

**Source:** Kravchenko, Lyerly, 2015
Coal-fired power plants in North Carolina:

- Significant decline in SO2 emissions (-20.3%/year) and PM2.5 sulfate concentrations (-8.7%/year) since passage of the NC Clean Smokestacks Act.

- Emissions reduction were highest in Piedmont region where 9 of the 14 NC coal-fired plants are located.

- Reductions of emissions resulted in 1700 deaths prevented in 2012 (model estimate).
We still need to work on the issues related to coal-fired power plants and health hazards in North Carolina.
Coal ash impoundments in North Carolina

- Coal plants hold coal ash in ponds or impoundments that can be located next to waterways and communities.
- Many impoundments have been found to be structurally inadequate and many have been found to be leaking toxins into ground and nearby surface waters.

(Source: www.Southeastcoalash.org)
Coal ash impoundments in NC

Out of 14 coal plants:

- 8 are rated by the EPA as highly hazardous (a dam failure is likely to cause loss of human life)
- 6 are rated as significantly hazardous (failure is likely to cause economic loss, environmental damage, or damage to infrastructure).

Additional concerns such as:

- Unlined impoundments that can easily leak toxic pollutants to nearby groundwater, rivers, and lakes.
- Impoundments contaminate groundwater, surface water, or soil above permitted levels.
In North Carolina, coal combustion residue (CCR) effluents, surface water from lakes and rivers and extracts from lake sediments contain high levels of contaminants. Coal-burning power plants and CCR disposal sites to waterways in NC (Ruhl, Vengosh, et al, 2012).

Concentrated ranges of selected contaminants in CCR effluents from coal-fired power plants in NC:

- red – plants with combined coal ash and flue-gas desulfurization systems,
- blue – only coal ash,
- green – reference lake (Jordan Lake),
- MCL – drinking water benchmarks,
• Isotope fingerprints and elevated levels of CCR traces provide strong evidence for the leaking of coal ash ponds to adjacent surface water and shallow groundwater in NC (Karkness, Sulkin, Vengosh, 2016).

• The NC DEQ (Department of Environmental Quality) proposed to classify 8 of Duke's coal ash ponds as high priority under the state's Coal Ash Management Act* (i.e., requiring excavation by 2019), and 25 as intermediate priority (i.e., requiring excavation by 2024).

*The Coal Ash Management Act was passed in 2014, following Duke's pond spill of coal ash into the Dan River.
Approximately 250,000 residents live in the communities located near coal power plants in NC.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Residents of NC communities with coal power plants: active</th>
<th>Residents of NC communities with coal power plants: retired</th>
<th>Residents of NC communities: control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median household income</td>
<td>$40,932**</td>
<td>$42,689**</td>
<td>$45,405</td>
</tr>
<tr>
<td>Bachelor or higher degree education</td>
<td>14.8%**</td>
<td>22.3%</td>
<td>23.8%</td>
</tr>
<tr>
<td>Availability of primary care providers (per 100,000 population)</td>
<td>51**</td>
<td>76</td>
<td>76</td>
</tr>
<tr>
<td>Percent of uninsured individuals</td>
<td>17.9%</td>
<td>18.5%</td>
<td>17.9%</td>
</tr>
<tr>
<td>Smokers prevalence among those aged 24+ years old</td>
<td>24.4%</td>
<td>25.6%</td>
<td>24.4%</td>
</tr>
</tbody>
</table>

Note: * - 0.001<p<0.05; ** - p<0.001.
## Mortality among the residents of NC communities located in close proximity to coal plants, per 100,000, 1999 vs. 2016.

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Year 1999</th>
<th>Year 2016</th>
<th>Mortality Rate Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall mortality rate, age 45-64</td>
<td>759.4 (13.9)</td>
<td>765.3 (11.8)</td>
<td>Δ=65.3</td>
</tr>
<tr>
<td></td>
<td>(13.9)</td>
<td>(11.8)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>694.1 (7.2)</td>
<td>618.7 (↓) (5.3)</td>
<td>Δ=146.6</td>
</tr>
<tr>
<td>Respiratory mortality, age 15-44</td>
<td>15.8 (1.5)</td>
<td>20.1 (↑) (1.8)</td>
<td>Δ=2.7</td>
</tr>
<tr>
<td></td>
<td>(1.5)</td>
<td>(1.8)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>13.1 (0.7)</td>
<td>13.2 (0.7)</td>
<td>Δ=7.9</td>
</tr>
<tr>
<td>Respiratory mortality, age 45-64</td>
<td>142.8 (6.0)</td>
<td>168.1 (↑) (5.5)</td>
<td>Δ=9.4</td>
</tr>
<tr>
<td></td>
<td>(6.0)</td>
<td>(5.5)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>133.4 (3.2)</td>
<td>134.9 (2.5)</td>
<td>Δ=33.2</td>
</tr>
</tbody>
</table>

Note: ¹standard error.
Respiratory mortality in NC communities located in close proximity to coal power plants: 15-44 y.o., age-adjusted rates (per 100,000), underlying +secondary cause of death, 1999-2016.

Potentially contributing factors:
- Cigarette smoking/E-cigarette
- Exposure from the coal ash ponds
- Poorer access to medical care for respiratory disease treatment
- Labor migrants
- Other exposures (e.g., PM components from the smokestacks)?
Mortality, hospital admissions, and ED visits odds ratios (ORs) in communities located near coal power plants in NC (compared to control group).

Adjusted by income, education, health insurance, primary care availability, and smoking prevalence.

Mortality:
- Respiratory diseases
  OR up to 5.94 (p=0.0059), depending on age group
- Asthma
  OR up to 3.65 (p=0.0144)

Hospital admissions:
- Respiratory disease
  up to 1.20 (p<0.0001), depending on age group
- Asthma
  up to 1.46 (p<0.0001)

ED visits:
- Respiratory disease
  up to 1.04 (p<0.0001), depending on age group
- Asthma
  up to 1.15 (p<0.0001)
# Summary of Prioritized Study Directions on Evaluation of Health Impacts of Coal-Burning Power Plants in North Carolina

<table>
<thead>
<tr>
<th>The aspects of future studies</th>
<th>Brief description of study directions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information needed for</td>
<td></td>
</tr>
<tr>
<td>▪ What are the ranges of community level and individual-level exposures to air contaminants and policy updates associated with emissions in NC communities located in close proximity to coal-burning power plants?</td>
<td></td>
</tr>
<tr>
<td>▪ What are the ranges of community level and individual-level exposures to water (well water, surface water, and groundwater) and soil contaminants associated with coal ash storage sites in NC communities located in close proximity to these sites?</td>
<td></td>
</tr>
<tr>
<td>▪ <strong>Are there increased risks of incidence of and/or mortality from certain diseases associated with coal power plant emissions or coal ash impoundments in NC</strong>? How do these risks change in NC respective to changes in the levels of air and water or soil pollutants?</td>
<td></td>
</tr>
<tr>
<td>▪ What will be the results of projections of potential health benefits in NC populations (at different scale - from community to county and to NC) if emissions from coal power plants are further reduced and lining and dam conditions at coal ash storage sites are improved?</td>
<td></td>
</tr>
<tr>
<td>▪ What will be the costs of health benefits resulting from improving environmental conditions at coal-burning power plants?</td>
<td></td>
</tr>
<tr>
<td>▪ What is the association between the distance from coal power plant or coal ash impoundments and health effects that can be quantified precisely?</td>
<td></td>
</tr>
<tr>
<td>Diseases/health outcomes of primary interest</td>
<td>Variables of primary interest</td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>------------------------------</td>
</tr>
<tr>
<td>• Respiratory disease, with specific focus on asthma, chronic bronchitis, emphysema, pneumonia, and influenza. Age-group specific analysis in children, young adults (21-44 years old), people aged 45-64, and over 65.</td>
<td>• Community based survey that would provide individual information on symptoms, quality of life, availability of medical care, history of residence, local water/food consumption, time spent outdoors, and occupational exposure.</td>
</tr>
<tr>
<td>• Lung cancer, with histologic subtype analyses, stage at diagnosis, access and adherence to treatment, and patient survival.</td>
<td>• Information on disease incidence, prevalence, severity, hospital admissions, ED visits, and mortality.</td>
</tr>
<tr>
<td>• Cardiovascular disease, including ischemic heart disease, myocardial infarction, cardiac arrhythmia, and heart failure. Age-group specific analysis among younger residents (aged 21-44), people aged 45-64, and over 65.</td>
<td>• Individual-level information on co-factors including income, education, smoking, etc.</td>
</tr>
<tr>
<td>• Maternal and child health: pregnancy complications, low birth weight, infant mortality, developmental and behavioral disorders in children.</td>
<td>• Monitoring of health of populations living near retired and active coal-burning power plants in NC for further assessments of health.</td>
</tr>
<tr>
<td>• Premature mortality.</td>
<td></td>
</tr>
</tbody>
</table>
Environmental measures/assessments to be further analyzed with health data

- Measures of NO\textsubscript{x}, SO\textsubscript{2}, PM\textsubscript{2.5}, PM\textsubscript{2.5-10}, and PM\textsubscript{10} levels in the air
- Analysis of different types of PMs (by their chemical compounds) and their associations with specific health outcomes.
- Measurements of PAHs\textsuperscript{1}, heavy metals, and radioactive isotopes in CCR\textsuperscript{2} effluents, potentially contaminated surface waters (from lakes and rivers), and pore water extracted from lake sediments.

Weather/climate-related factors to account for in future studies on health impacts

- Season-specific analysis, including summer months in NC with heat waves and high humidity.
- Events of heavy rains and floods in the areas where coal ash impoundments are located.

\textsuperscript{1}polycyclic aromatic hydrocarbons.
\textsuperscript{2}coal combustion residues.
Acknowledgements

• Duke Environmental Health Scholars Program
• Clean Air Carolina
• North Carolina Division of Air Quality

• We thank Igor Akushevich (Duke SSRI, Duke University) for his help in analysis.

• We thank Fred and Alice Stanback for supporting this study with a philanthropic donation.

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WOW!
A BOTTLE OF FRESH AIR!
I LOVE IT!