

**Capturing Carbon But Not Its Co-Pollutants:
CCUS in the Electricity System and the Challenge of Just Decarbonization**

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We will investigate how the application of Carbon Capture, Use, and Sequestration (CCUS) technology in the US electricity system may affect local pollution with a focus on Environmental Justice (EJ) communities. We examine alternative technologies and policies that can achieve both carbon reduction and local air-quality co-benefits with attention to environmental justice. We conduct a policy analysis with a range of plausible policy alternatives and combine: sophisticated technical and economic modeling of the electricity system; high-quality modeling of local pollution impacts; and sensitivity analysis of technological and policy uncertainties.

CCUS technology may advance decarbonization (IPCC, 2018) with the potential to reduce 90% of carbon emissions from combustion-based electrical generation (Energy Futures Initiative, 2020), which would, if applied to all existing plants, reduce total US carbon emissions by roughly one third (EIA, 2022). While the cost- and carbon-effectiveness of CCUS is subject to active debate, the US DOE and the Biden Administration are interested (Council on Environmental Quality, 2021; The White House, 2021). Environmental Justice advocates have expressed great concern about CCUS (Center for International Environmental Law, 2021). Current CCUS technologies remove carbon from the pollution stream but ignore local co-pollutants. This means, while CCUS may improve carbon performance, other air-pollution problems from the same emitter remain, with particular consequences for vulnerable communities. Some proposed CCUS technologies may also reduce co-pollutant emissions, but data on co-pollutant co-reductions from CCUS are mostly proprietary, and further studies are necessary (Energy Futures Initiative, 2020). Although in this proposal we focus on the carbon-capture portion of CCUS, that is, the removal of CO₂ from emissions streams, we use the term CCUS throughout. The use and sequestration components of CCUS also have important EJ implications which future research should pursue.

While CO₂ emissions affect the entire planet regardless of the source location, co-pollutants are harmful for those directly exposed, usually living near the emitters. The disproportionate exposure and residential proximity of people of color and low-income people to air pollution from industrial facilities, including the power sector, is well documented in the US (Ash, 2009; Boyce, 2013; Richmond-Bryant, 2020). Concerns regarding the unintended environmental injustice of carbon policies in the US are not unfounded. Prior work has found that pollution policies that fail to account for more localized co-pollutants and their inequitable distribution may increase exposures in specific localities and exacerbate environmental injustice (Diana, Ash, & Boyce, 2021). Spatial mismatch in environmental policy, that is, between the scale and scope of global and local pollutants and their regulation, and the potential for policy itself to create pollution hotspots—in particular for environmental justice communities—was already a concern in the market-based SO₂ reduction policies implemented in the Clean Air Act Amendments of 1990. California's RECLAIM, a cap and trade program for NO_x and SO_x that implemented zonal restrictions on trading to avoid hotspots (Zabin, Martin, Morello-Frosch, Pastor, & Sadd, 2016), had some apparent success with respect to environmental justice (Cushing, et al., 2018).

The purity of greenhouse gasses (GHG) as a global public bad makes the threat of policy mismatch for local environmental harms all the greater. There is evidence that carbon-permit trading has already exacerbated environmental inequality in California's carbon cap and trade program (AB32), one of the most ambitious market-based decarbonization policies in the country (Cushing et al., 2018; Boyce & Ash, 2018; Diana et al., 2021).

Regardless of its effectiveness for carbon reduction, CCUS that maintains the *status quo* in local air pollution will not be acceptable to vulnerable communities that have been promised a substantial benefit from climate-crisis response with the Biden administration committed to equity and justice in energy transition policies (OCCHE, 2021; The White House, 2021).

The debate over CCUS is thus trilateral, with some supporting it as a savior technology, others skeptical regarding technical and economic feasibility, and others concerned with its narrowness and inequity relative to the breadth and distribution of environmental challenges. The EJ debate over CCUS creates an opportunity to evaluate the role of technological uncertainties, policy design, and distributional equity in the deployment of CCUS.

Research Questions and Contributions to the Literature

Our central research questions are: How would the availability of CCUS mediate the relationship between environmental policy and local pollution, especially in EJ communities? How can the policy and technical implementation of CCUS be structured to maximize local health benefits, in particular to EJ communities, while also realizing the climate benefits of GHG reduction?

The academic literature on CCUS has focused on technical aspects and cost effectiveness of the technology on individual facilities or processes (Peridas & Schmidt, 2021; Tapia et al., 2018). A few studies capture how CCUS may alter the operation of a local grid, for example, shifting activity from one electrical-generation node to another (Wei, et al., 2016; Ji, et al., 2013; Asgharian & Abdelaziz, 2019). Networked electrical systems can manifest counterintuitive behaviors (Downward, 2010), meaning new technology and policy should include the potential for network effects (Weare, 2003). While there is a large literature on energy justice (Jenkins, 2021; Miller, 2014), the literature addressing carbon capture and EJ is conceptual rather than grounded in the complexities of the electricity system (Batres, et al., 2021). Our work bridges these gaps by combining a transmission network model with detailed geographical data, allowing us to address distributional justice of CCUS investment and operation, which depend crucially on the context of specific locations.

Using sophisticated modeling of both the electricity system and its spatially-specific pollution impact, we investigate these questions under a range of assumptions about the characteristics of CCUS, the characteristics of the local grid and surrounding communities, and different policies. Drawing from our previous large-scale analysis of the electricity sector (Diana et al., 2021), we will undertake three local case studies of electricity-sector transformation in the continental US to explore the magnitude and distribution of local pollution impacts of decarbonization. We will examine how alternative policies would affect GHG emissions, local air quality, and environmental justice (the social distribution of local air pollutants). We will conduct sensitivity analysis reflecting technological uncertainty for CCUS, a new technology, including investment costs, operation costs, and rate of co-pollutant emissions. Combining technology and policy analysis can shed light on how CCUS might be applied in the context of a just energy transition, helping to decarbonize the power grid, advance climate goals, and protect and improve the environment in EJ communities.

Research Design and Methodology

This work combines power systems modeling, integrated assessment modeling of population exposure to local pollution, and policy and uncertainty analysis. We apply our models to real-life case studies, to understand the impacts of local characteristics. We develop a three-node model of the power system, incorporating key aspects such as transmission, ramping, start-up costs, unit commitment, and apply it to local co-pollutant and environmental justice analysis of three localities, chosen based on previous work by Diana et al., (2021). We will parameterize the model to match the three study areas, investigating combinations of coal, natural gas, and renewable energy.

1. Case Studies of Local Grids, Pollution, and EJ

The case study candidates emerge from our earlier large-scale quantitative research that demonstrated the potential for increased airborne emissions and pollution inequality under policies that consider only a carbon target and neglect local co-benefits and EJ. Local context was enormously important for mediating the linkage between carbon and co-pollutant reductions; with carbon intensity, substitution across fuels and facilities, and the proximity of expanding and contracting facilities to populations as the key factors in divergence (Diana et al., 2021).

We will select a set of case studies to analyze pollution from combustion-based electrical generating facilities and the share of the pollution burden borne by EJ communities. Our national analysis identified a case study in Georgia where the nation's highest CO₂-emitting coal plant, Scherer, is surrounded by 2,324 people, of whom 20% are Black, 13% are Hispanic, and 48% are low income. In contrast, yet also in Georgia, the nation's second highest CO₂-emitting natural gas plant, McDonough-Atkinson, is surrounded by 60,340 inhabitants of whom 40% are Black, 8% are Hispanic, and 25% are low income. After reviewing our study, the National Black Environmental Justice Network (NBEJN, 2022) identified another case of interest: the Barry Steam Power Plant (a large plant from the 1950s that now burns both coal and gas) and the Hog Bayou Energy Center (a 21st-century gas-fired plant). Both facilities are in the vicinity of Mobile, Alabama. Barry is about 10 times bigger in terms of installed capacity and annual generation, 15 times in terms of CO₂, and 20 times in terms of particulate-matter releases. But Hog Bayou is surrounded (within 15 km) by 25 times the population of Barry, and the nearby population (5 km) is 85% African American compared to 35% for Barry. We will parameterize the grid model for each case study, including the type, capacity, and network structuring of local electricity generation alongside demographic data.

2. Model of the Electricity Grid and Market with CCUS

We have developed a Direct Current Optimal Power Flow (DCOPF) model for a three-node network (See Figure 1 for an example). DCOPF is the core of many established power systems simulation tools and most suitable for analysis of transmission networks (Purchala et al., 2005). Our baseline model employs an objective function to minimize the cost of investment and operation decisions under the constraint of meeting electricity demand. Baseline model constraints will include the behavior of generators, loads, network links, and other interactions with the larger regional system, making this one of the first applications of sophisticated, accurate electricity-market modeling to GHG reduction, co-pollutant exposure, and environmental justice. Optimization methods will include integer programming, to account for discrete the investment decisions and for the commitment status of the generators. Loads and renewable resources will be considered deterministic.

Our CCUS model begins with parameters drawn from the literature given existing measurements, models, and predictions for technological improvement. We will consider investment costs (overnight costs for CCUS retrofit to existing Natural Gas and Coal, and for construction of new Natural Gas power plant coupled with CCUS), operation costs (energy penalty, CO₂ storage and transportation, and cost of adding co-pollutant sequestration technology), as well as the rate of emissions of CO₂, other greenhouse gasses, and co-pollutants (PM, NO_x, and SO_x). We will explicitly model different types of CCUS.

3. US EPA and EIA electricity and emissions data, air-plume fate-and-transport modeling and local impacts with integrated assessment models, and sociodemographic data from US Census

The US EPA eGRID 2020 database, to be released before March 2022, draws on data from the Energy Information Administration (EIA) (EPA, 2022). It includes facility-specific capacity and output (demand), total and rates of CO₂-equivalent greenhouse gas emissions, and totals and rates of local pollutant emissions figures. US EPA eGRID provides electricity generation, GHG, and local pollutant (SO₂, PM 2.5, and NO_x) data for each facility which can be inputs to the APEEP damage-estimate model.

The Air Pollution Emission Experiments and Policy (APEEP) model is a peer-reviewed integrative assessment model that provides spatially-specific monetized damage for the electrical generation sector, incorporating human-health impacts, agricultural impacts, and damage to physical capital; with health impacts constituting by far the largest share of damages (Muller & Mendelsohn, 2006; NRC, 2010)

Tract-level Summary File data from the U.S. Census and the American Community Survey (United States Census Bureau, 2022) enable spatially-specific socio-demographic analysis of populations near facilities and apportionment of health impacts from APEEP to environmental justice populations.

4. Scenarios, Policies, Parameters, and Sensitivity Analysis

We will perform multiple parameter sensitivity analyses under different emissions policies. We will experiment with incorporating policies as cap-like constraints; embedded in the cost function as monetized social costs along the lines of Pigouvian taxation; or included in a multi-criteria optimization. Each of these approaches has advantages and disadvantages, and we will pursue all of them. After multiple runs, the objective is to expose the trajectory of costs, investment decisions, generation mix, greenhouse gas emission level, co-pollutants emission levels and co-pollutant exposure by different socioeconomic groups

We will start by soft linking the APEEP model to the DCOPF models, as follows. For each set of policies and parameters, we will derive the energy generation portfolio from the DCOPF and feed the implied emissions into APEEP to get the EJ impacts. We will then evaluate the need to optimize over policies. In this case, we will build a surface based on the APEEP model and use this to optimize the DCOPF model. Specifically, we will use methods similar to Anadon, Chang & Lee (2014). We will use a sampling method over generation portfolios to develop a database of APEEP outputs. We will then estimate a functional form to represent the relationship between the generation portfolio and environmental and health outcomes. Then, we can optimize specifically for EJ outcomes, such as limiting the percent of local air pollution a socioeconomic group is exposed to be no more than its share in the state population.

Preliminary Results

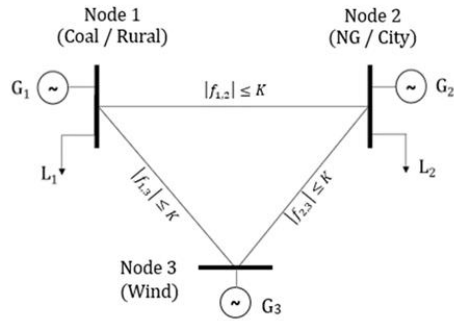


Figure 1. Symmetric three-node grid

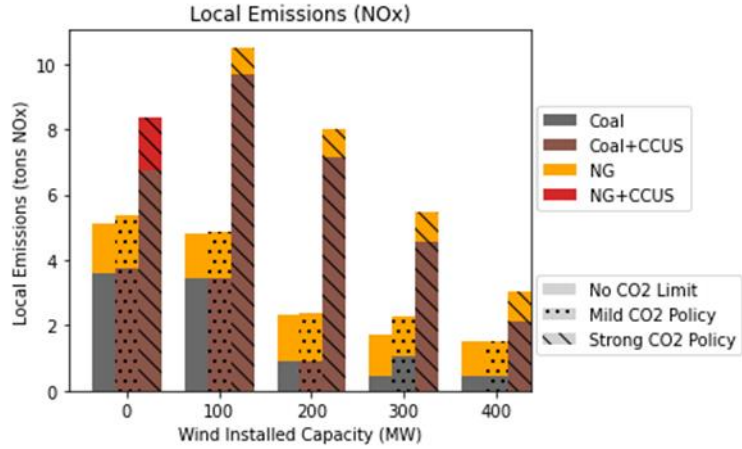


Figure 2. Co-pollutant emissions for different policies

In this illustrative example, two demand centers are served by three generators in a symmetric network loop (see Figure 1 above). We allow fossil fuel power plants to add carbon capture technology, for a cost, to achieve carbon-reduction targets. There is no opportunity for co-pollutants reductions via CCUS; we assume the facilities are already compliant with the Clean Air Act. Figure 2 shows how the local pollution changes as (1) more stringent carbon reduction goals are set; and (2) more wind energy is installed. We find increased local pollution under the most stringent climate goal. This is because the use of CCUS requires the retrofitted facility to produce more energy leading to higher emissions; while 90% of CO₂ is captured, the co-pollutants are fully discharged into the local area. We find a non-monotonic response to increased wind, with local pollution first increasing as wind increases, under a stringent carbon policy. This is because, with moderate amounts of wind it is most economic to use CCUS with coal rather than gas. As wind increases farther, energy from fossil fuel decreases to the point that local pollution decreases.

About the Lead Authors

The lead authors and co-recipients of the stipend, if awarded, are Paola Furlanetto and Bridget Diana, both at University of Massachusetts Amherst. Furlanetto is a Ph.D. student in Industrial Engineering, where she applies economics and mathematical modeling to energy equity topics. Originally from northeastern Brazil, Paola earned a Master of Science in Energy Systems with a focus on policy at Northeastern University and a Bachelor of Science in Electrical Engineering from the Federal University of Campina Grande in Brazil. Diana is a Ph.D. student in Economics, where she is a research assistant for the Political Economy Research Institute. She was the lead author on the PERI report *Green for All: Integrating Air Quality and Environmental Justice into the Clean Energy Transition*. Bridget earned a Bachelor's Degree *summa cum laude* from Denison University. Baker and Ash are the Faculty Directors of The Energy Transition Institute, focused on research at the intersection of energy technology and social equity.

Conflict of Interests

The authors have declared that no competing interests exist.

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