Clean Energy Futures: Many Paths, Different Outcomes

Why This Analysis Matters Now

With U.S. energy policy at a crossroads, the Clean Energy Futures (CEF) project aims to quantify the carbon emissions, costs, and co-pollutant outcomes of different electricity sector policy options.

Policy choices for addressing greenhouse gas (GHG) emissions from the electricity sector are front and center in current national conversations about climate change. The replacement of the Clean Power Plan with the current administration’s Affordable Clean Energy rule is being challenged in the courts. Both the House Select Committee majority report Solving the Climate Crisis and the climate plan of presidential candidate Joseph Biden call for reaching zero carbon emissions from the electricity sector within the next two decades and net-zero GHG emissions economy-wide by 2050.

The CEF project explores tradeoffs among electricity sector policies to mitigate carbon emissions that are relevant to current national discussions.

What’s at Stake?

Electrification of the transportation, building, and industrial sectors has emerged as a central strategy for decarbonizing the U.S. economy. With this transition, electricity sector policy will strongly influence U.S. carbon emissions, air quality, and related human and ecosystem health outcomes in the future.

- Internationally, electricity sector policy will determine whether the U.S. gets back on track to meet its original commitment under the Paris Climate Accord.
- Nationally, electricity sector policy will define the nation’s energy technology pathway of the future, the timeline for decarbonization, the cost of electricity to consumers, and national emissions outcomes.
- For states, electricity sector policy will influence their ability to achieve GHG-reduction and air quality goals.
- Locally, national electricity sector policy will perpetuate or help alleviate longstanding inequalities in exposure to air pollution.

The Clean Energy Futures Project

The CEF project is a multi-institutional research initiative with experts from Syracuse University; Center for Climate, Health, and the Global Environment at the Harvard T.H. Chan School of Public Health; Resources for the Futures; and Georgia Institute of Technology.

The CEF team is analyzing 10 leading policy approaches to reducing carbon dioxide (CO₂) emissions from the electricity sector: (1) recent rules promulgated by the U.S. Environmental Protection Agency (EPA), (2) clean electricity standards, (3) national cap and trade policies, and (4) carbon prices in the electricity sector (Table 1).

Each electricity sector policy is compared to a no-policy reference case (business as usual, BAU) to estimate changes in: (1) CO₂ emissions; (2) electricity system generation sources and system costs; (3) co-pollutant emissions of sulfur dioxide (SO₂), nitrogen oxides (NOₓ), and mercury emissions; (4) air quality; and (5) air quality-related human and ecosystem health outcomes. This policy brief reports on items 1-3 and also provides estimated social impact of electricity sector emissions changes (Table 2).
Key Insights

- Clean energy policies that reach low or zero carbon emissions in the electricity sector by 2040 to 2050 are achievable at a cost of about 15% above baseline and generate climate and health benefits that far exceed the moderate policy costs.
- By comparison, the existing Affordable Clean Energy rule does little to address carbon dioxide emissions nationally and is projected to increase carbon and co-pollutant emissions in many states.
- National policy design matters to the timing and magnitude of carbon emissions reductions, costs, and air quality in individual states.

Table 1. Clean Energy Futures Policy Scenarios.

<table>
<thead>
<tr>
<th>Policy Type</th>
<th>Label</th>
<th>Policy Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>No-policy reference case</td>
<td>BAU</td>
<td>No policy covering electricity sector carbon emissions beyond existing state/regional policies</td>
</tr>
<tr>
<td>Regulation</td>
<td>ACE</td>
<td>Affordable Clean Energy (ACE)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Source based: 4.5% HRI for affected units</td>
</tr>
<tr>
<td></td>
<td>CPP20</td>
<td>Updated Clean Power Plan (CPP)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>System based: updated CPP to achieve 65% emission reduction from 2005 levels by 2035</td>
</tr>
<tr>
<td>Clean Electricity Standard</td>
<td>CES40</td>
<td>Threshold of 0.82 metric tons/MWh, partial crediting, 100% clean in 2040, based on total generation, no banking</td>
</tr>
<tr>
<td></td>
<td>CES40-B</td>
<td>Threshold of 0.82 metric tons/MWh, partial crediting, 100% clean in 2040, based on total generation, banking 2025-2050</td>
</tr>
<tr>
<td></td>
<td>CES50-H</td>
<td>Threshold of 0.82 metric tons/MWh, partial crediting, 100% clean and zero-emission requirement in 2050, based on total generation, banking allowed 2025-2040</td>
</tr>
<tr>
<td></td>
<td>CES50-L</td>
<td>Threshold of 0.46 metric tons/MWh, partial crediting, 100% clean and zero-emission requirement in 2050, based on total generation, banking allowed 2025-2040</td>
</tr>
<tr>
<td>National cap and trade</td>
<td>CAP</td>
<td>Zero CO₂ emissions by 2050, national trading, no banking, offsets allowed 2040-2050</td>
</tr>
<tr>
<td></td>
<td>CAP-B</td>
<td>Zero CO₂ emissions by 2050, banking allowed</td>
</tr>
<tr>
<td>Carbon Price</td>
<td>CP-25</td>
<td>$25/ton, rises at 5% per year</td>
</tr>
<tr>
<td></td>
<td>CP-50</td>
<td>$50/ton, rises at 5% per year</td>
</tr>
</tbody>
</table>

The Policy Scenarios and Approach

The national electricity sector policies examined in the CEF project represent a range of regulatory and market-based approaches, and include varied assumptions about the target and timeline for emissions reductions, the size of the units considered for emission controls, use of banking, and other policy-specific factors (see Table 1 and Supporting Information for details).

For each policy, simulations were conducted with the Integrated Planning Model (IPM) to estimate changes in capacity, the generation mix across energy sources, and CO₂ and criteria pollutant emissions.
for 2020 to 2050. Estimated state-level emissions in 2030 and 2050 were combined with unweighted state average marginal social cost estimates produced using the EASIUR model to estimate the social impact of changes in criteria pollutants (Heo et al., 2016). Work is underway to simulate air quality impacts for each of the policy cases using the Community Multi-Scale Air Quality Model (CMAQ). CMAQ results will be used to estimate health benefits using a version of the Benefits Analysis and Mapping Program (BenMAP) (See Text box below and Supporting Information for methods).

Table 2. Key Results for 10 Policy Scenarios Compared to a No-policy Reference Case.

<table>
<thead>
<tr>
<th>Policy Type</th>
<th>Label</th>
<th>Cumulative Emission Reductions 2020-2050</th>
<th>Incremental PV Cost (% of BAU)</th>
<th>PV of Net Benefits (Billion $)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>CO₂</td>
<td>NOₓ</td>
<td>SO₂</td>
</tr>
<tr>
<td>No-policy reference case</td>
<td>BAU</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Regulation</td>
<td>ACE</td>
<td>&lt;1 Gt</td>
<td>&lt;1 Mt</td>
<td>&lt;1 Mt</td>
</tr>
<tr>
<td></td>
<td>CPP20</td>
<td>16 Gt</td>
<td>10 Mt</td>
<td>14 Mt</td>
</tr>
<tr>
<td>Clean Electricity Standard</td>
<td>CES40</td>
<td>31 Gt</td>
<td>16 Mt</td>
<td>21 Mt</td>
</tr>
<tr>
<td></td>
<td>CES40-B</td>
<td>33 Gt</td>
<td>17 Mt</td>
<td>25 Mt</td>
</tr>
<tr>
<td></td>
<td>CES50-H-B</td>
<td>25 Gt</td>
<td>14 Mt</td>
<td>19 Mt</td>
</tr>
<tr>
<td></td>
<td>CES50-L-B</td>
<td>27 Gt</td>
<td>14 Mt</td>
<td>19 Mt</td>
</tr>
<tr>
<td>National cap and trade</td>
<td>CAP</td>
<td>34 Gt</td>
<td>16 Mt</td>
<td>22 Mt</td>
</tr>
<tr>
<td></td>
<td>CAP-B</td>
<td>35 Gt</td>
<td>17 Mt</td>
<td>25 Mt</td>
</tr>
<tr>
<td>Carbon Price</td>
<td>CP-25</td>
<td>26 Gt</td>
<td>16 Mt</td>
<td>22 Mt</td>
</tr>
<tr>
<td></td>
<td>CP-50</td>
<td>34 Gt</td>
<td>17 Mt</td>
<td>25 Mt</td>
</tr>
</tbody>
</table>

Summary of Results

Carbon Dioxide Emissions and System Costs

Marked differences exist in estimated national CO₂ emissions from the electricity sector across the policy cases (Figure 1a). Consistent with past analysis by the U.S. EPA and CEF, at a national scale ACE is indistinguishable from the no-policy option (Keyes et al. 2019, Lambert et al., 2019). In 2050, the updated Clean Power Plan and the $25/ton case achieve estimated CO₂ emissions reductions that are mid-way between ACE and the low-emission policies. Seven policies with different policy designs reach zero or near-zero CO₂ emissions by 2050. These “clean energy policies” for the electricity sector include the $50 per ton carbon price (CP-50), the two zero-emissions cap and trade policies, and the four 100% clean energy standards (CES).

In the early simulation years (2025-2030), large variations in CO₂ emissions are evident among the clean energy policies (Figure 1a). Policies without banking and a 2040 target for zero emissions (CES40 and CAP) reach their CO₂ targets earliest. Policies that allow banking until 2050 (CES40-B and CAP-B)
achieve larger early reductions, but are characterized by higher emissions from 2040 to 2050 as banked allowances that accumulate before 2040 are depleted. The remaining two clean energy policies (CE50-H and CES50-L) have a 2050 target year for 100% clean, use different carbon intensity benchmarks for what qualifies as “clean”, and allow banking but only until 2040. Because banking is allowed over a short period and is terminated before it would be most valuable (i.e., 2050), it plays a smaller role in these policies than in the other banking scenarios.

Figure 1. Time series of (a) carbon dioxide emissions and (b) system costs for policy options to decrease carbon dioxide emissions from the electricity sector.
The emissions patterns described here reflect changes in generation sources that are projected to occur under each scenario. Under ACE, coal and natural gas generation persist at 2020 levels through 2050. All other policies drive out coal by 2030-2035. A notable difference among the clean energy policies is the extent to which coal generation is replaced by natural gas (with and without carbon sequestration and storage) versus renewable sources, largely solar and wind (see Supporting Information on generation for details). In general, policies with banking have more generation from fossil fuel sources in 2040 and 2050 compared to those where banking is not implemented.

Carbon dioxide is a global pollutant and local emissions do not directly result in local impacts, but many states have established GHG reduction goals (Center for Climate and Energy Solutions, 2020). The ability of states to achieve these goals may be influenced by national electricity sector policies. Under ACE, CO2 emissions could increase by up to 20% in several states, consistent with prior estimates of ACE impacts based on EPA modeling (EPA, Keyes et al. 2019, Lambert et al. 2019). In contrast, all states see substantial emissions reductions under the clean energy policies (Figure 2).

**Figure 2.** Change in CO2 emission by state for selected energy policy scenarios compared to a no-policy reference case in (a) 2030 and (b) 2050.
System costs include the cost of fuel, building new capital projects and retrofitting existing facilities, and operating energy facilities. Policies with banking have higher annual system costs in 2025 as utilities reduce emissions in the near term in order to bank permits for the future, but then have lower costs in later years given access to banked allowances in 2040 to 2050 (Figure 1b).

The policy options cluster in three groups from low to high cumulative CO₂ emissions reductions and system costs for 2020 to 2050 (Figure 3). The cumulative system costs of the high ambition clean energy policies are 13-18% higher than costs under the no-policy reference case (Table 2).

![Figure 3. Present value systems costs as a function of cumulative reductions from 2020 to 2050 in CO₂ for the electricity sector policy options and a no policy scenario. The policies cluster into groups of low (red), moderate (blue) and high (green) ambition groups.](image)

Co-Pollutant Emissions and Social Impacts

Policies that influence CO₂ emissions also affect emissions of SO₂, NOₓ, mercury and other pollutants that arise from combustion of fossil fuels. These co-pollutants can have large local to regional effects on air quality and human and ecosystem health. SO₂ and NOₓ emissions contribute to smog formation, including fine particulate matter and ozone, and harm human health. These pollutants also contribute to acid rain and the eutrophication of fresh and coastal waters. Mercury emissions and deposition promote the bioaccumulation of mercury in fish and increase exposure of people and wildlife to this toxic substance.

Estimated changes in SO₂ emissions under the policies mirror the emissions trends of CO₂ from 2020 to 2050 (Figure 4a). This pattern reflects the close coupling of SO₂ emissions with coal use. Mercury emissions follow a similar pattern. Coal generation is essentially eliminated in the clean energy policies by 2030-2035 and SO₂ and mercury emissions decline accordingly.

Nitrogen oxide (NOₓ) emissions diverge from the patterns of SO₂ and mercury by showing more variation among the clean energy policies because coal is not the only driver of NOₓ emissions (Figure 4b). Natural gas can be a large source of NOₓ emissions and the clean energy policies differ in the technology pathways and generation sources used. In all of the policies examined here, small generating units with capacity below 25MW, which can be significant sources of NOₓ, were not allowed
to exceed their BAU generation rates. If these units were exempted from the policy and allowed to generate without constraint, NO\textsubscript{x} emissions would be higher. This will be a topic of future analysis.

State level SO\textsubscript{2} and NO\textsubscript{x} emissions vary by energy policy (Figure 5a-b, Figure 6a-b). Under ACE, "emissions rebound" from fossil fuel facilities drive emissions increases in many states. Some clean energy policies show slight increases in SO\textsubscript{2} and NO\textsubscript{x} emissions in some states in 2030, but these increases are temporary and are not large enough to adversely affect air quality.

**Figure 4.** Time series of (a) sulfur dioxide (SO\textsubscript{2}) and (b) nitrogen oxide (NO\textsubscript{x}) emissions for policy options to decrease carbon dioxide emissions from the electricity sector.
Figure 5. Change in SO₂ emission by state for selected energy policy scenarios compared to a no-policy reference case in (a) 2030 and (b) 2050.

a. 2030

b. 2050
Figure 6. Change in NOx emission by state for selected energy policy scenarios compared to a no-policy reference case in 2030 (a) and 2050 (b).

a. 2030

b. 2050
Social impact estimates

Estimates of social impacts associated with changes in state emissions incorporate changes in both \( \text{NO}_x \) and \( \text{SO}_2 \) emissions using EASIUR. Importantly, the map of EASIUR results in Figure 8 indicates where social impacts originate, not where they occur (that is, benefits are based on the states where emissions occur, which may differ from the states where populations downwind are affected). Under ACE there are no estimated benefits from changes in state emissions, rather disbenefits occur due to anticipated \( \text{SO}_2 \) and \( \text{NO}_x \) emissions rebound in several states (Keyes et al. 2019) (Figure 8). Decreases in \( \text{SO}_2 \) emissions are responsible for much of the estimated benefits in the other policy cases. \( \text{SO}_2 \) decreases linearly with coal generation, all the clean energy policies are projected to increase social benefits estimated for all states, particularly in the Midwest, Florida, and Texas. States with estimated emissions changes that contribute decreases in benefits under the clean electricity policies experience large air quality improvements compared to the ACE (see air quality text box). By 2050, all states have increases in benefits under the clean energy policies (Figure 8b).
Figure 8. Estimated benefits by state of origin (not impact) due to changes in SO₂ and NOₓ emissions in (a) 2030 and (b) 2050.

Aggregate Costs and Benefits

Estimates of present value costs and social impacts from the reduction of damages associated with decreases in CO₂, SO₂ and NOₓ emissions were calculated over the period 2020 to 2050 for ACE and the clean energy policies (Figure 8). The benefits of reductions in CO₂ emissions are calculated using a constant real social cost of carbon of $50 in 2019 dollars. The benefits of reductions in SO₂ and NOₓ emissions are based on the central marginal cost values in EASIUR.
The results show that ACE has little to no benefits. In contrast, the benefits from emissions reductions are large and far outweigh the costs for all the clean energy policies. Note, aggregate measures do not depict the full impact of the policies given that they do not account for local variations. Therefore, these results should be considered in context with state-based results presented here. Detailed air quality and health modeling will be forthcoming in the next phase of this analysis.

**Figure 8. Estimated present value system costs and monetized climate and health benefits of ACE and clean energy policies compared to a no-policy reference case over 2020 to 2050.**

---

**Summary**

- Clean energy policies that reach low or zero carbon emissions in the electricity sector by 2040 to 2050 are achievable at a cost of about 15% above baseline and generate climate and health benefits that far exceed the moderate policy costs.
- By comparison, the existing Affordable Clean Energy rule does little to address carbon dioxide emissions nationally and is projected to increase carbon and co-pollutant emissions in many states.
- National policy design matters to the timing and magnitude of carbon emissions reductions, costs, and air quality in individual states. Specifically:
  - All high-ambition policies drive down coal generation by 2030-2035 resulting in large reductions in emissions of SO₂ and mercury.
  - Policies with stringent targets and timelines with no banking reach the zero- or near-zero CO₂ emission target rapidly but have higher costs and lower cumulative emission reductions.
  - Banking lowers costs, and together with a stringent policy target achieves early emissions reductions and larger cumulative emissions reductions. It also results in higher generation from fossil fuel sources and has slightly elevated co-pollutant emissions compared to the no-banking policies in the later years (2040-2050).
Next Steps for the Clean Energy Futures Project

- Publish policy analysis paper
- Develop additional policy briefs on the influence of small generating units and the effects of different clean energy standard policy designs
- Model air quality changes for all policy cases
- Model human and ecosystem health outcomes
- Analyze distributional effects for cost and air quality outcomes by race/ethnicity and income

References


Collaborators and Acknowledgements

- Charles Driscoll, Jr. – Science lead, University Professor of Environmental Systems and Distinguished Professor of Civil & Environmental Engineering, Syracuse University
- Kathy Fallon Lambert – Policy engagement lead, Senior Advisor, Center for Climate, Health, and the Global Environment at the Harvard T.H. Chan School of Public Health
- Dallas Burtraw – Darius Gaskins Senior Fellow, Resources for the Future
- Maya Domeshek – Research Associate, Resources for the Future
- Amelia Keyes – Research Associate, Resources for the Future, JD candidate Harvard Law School
- Qasim Mehdi – PhD candidate, Syracuse University
- Armistead (Ted) Russell – Regents Professor, Georgia Institute of Technology
- Huizhong Shen – Postdoctoral Fellow, Georgia Institute of Technology
- Peter Wilcoxen – Professor, Director of the Center of Environmental Policy and Administration, Maxwell School, Syracuse University
- Petros Vasilakos – Postdoctoral Fellow, Georgia Institute of Technology

IPM simulations were conducted by ICF. The Clean Energy Futures project is solely responsible for the scenario specifications and all assumptions used in the IPM analysis.