CENTER FOR GLOBAL SUSTAINABILITY
SCHOOL OF PUBLIC POLICY

# U.S. Clean Energy Policy Rollbacks

## The Economic and Public Health Impacts Across States

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## TECHNICAL APPENDIX

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# 1. Overview of Modeling Approach

Building on CGS's previous analyses,[40,41] this study examines the impacts of federal clean energy policy rollbacks on human health and the economy and explores the distribution of these impacts across states through an innovative, integrated approach. In a close collaborative effort with research teams at Princeton University and the University of Maryland Geographical Sciences Department, this approach combines 1) **GCAM-USA-CGS**, a field-leading, integrated assessment model with 50-state resolution in the United States, 2) **InMAP and BenMAP**, an air quality and health impacts model to simulate air pollutant concentration and quantify health damages, and 3) **IMPLAN,** an Input-Output model to perform economic impact analysis across 50 states. Detailed descriptions of the models used are included in sections 5-7.

**GCAM-USA-CGS:** Our analysis uses a version of the open-source Global Change Analysis Model (GCAM) to estimate the aggregate impact of federal and non-federal climate policies and actions on economy-wide emissions reductions in the United States. Specifically, we use GCAM-USA, a state-level version of GCAM. We refer to the version of GCAM-USA used in this study as GCAM-USA-CGS, which is based on the open-source release of GCAM-USA 6.0. GCAM-USA-CGS has been updated for the purposes of this study to reflect changes such as the most recent estimates of future renewable energy costs and non-$CO_2$ marginal abatement costs.

**InMAP and BenMAP:** To estimate the air quality and health impacts of emissions across the U.S., we use a spatially explicit modeling framework combining downscaled emissions with the Intervention Model for Air Pollution (InMAP), a reduced-complexity, national-scale air quality model. State-level emissions projected by GCAM-USA-CGS are downscaled to a 12-km grid using spatial patterns from the 2017 National Emissions Inventory (NEI). InMAP then simulates annual average concentrations of both primary and secondary PM2.5 (including sulfate, nitrate, and ammonium), solving a steady-state version of the reaction-advection-diffusion equation. This approach captures pollutant transport by wind, atmospheric diffusion, and chemical transformation. Simulated PM2.5 concentrations are then used in EPA's Environmental Benefits Mapping and Analysis Program – Community Edition (BenMAP-CE) to estimate county-level premature deaths due to long-term PM2.5 exposure, using established concentration-response functions such as those from Krewski et al.

**IMPLAN:** Through modeling inter-regional industrial linkages and trade flow characteristics, this input-output model comprehensively assesses the overall impacts of energy transition on GDP and household income across states.[1] To incorporate the GDP and labor income effects of the energy transition under both scenarios, we match 14 sectors in GCAM-USA-CGS (mainly electricity generation and end use sectors of natural gas, refined liquids, coal, and biomass) to the 11 energy sectors in IMPLAN, and then use a Leontief inverse matrix to trace the GDP, and labor income effect of the energy transition. This approach assesses the macroeconomic impacts of the energy system transition on the supply side, including indirect impacts through the supply chain and induced impacts through income change. However, it does not cover the impacts associated with transitions occurring in the end-use sectors on the demand side, including EV battery manufacturing, and thus likely underestimates the overall economic effects under federal clean energy policy rollbacks.

[1]MIG, Inc. (2002) Elements of the Social Accounting Matrix. MIG IMPLAN Technical Report TR-98002.

## 2. Scenarios

Two distinct scenarios, based on previous CGS analyses, are modeled to represent the impacts of potential federal clean energy policy rollbacks.

The *Current Policies* scenario includes key, on-the-books clean energy policies at the federal and non-federal levels (as of December 2024). These include provisions in the IRA and BIL, EPA regulations on fossil fuel power plants and tailpipe emissions, and state-level policies such as renewable portfolio standards, zero-emission vehicle mandates, and building efficiency standards.

The *Federal Rollbacks* scenario assumes a complete repeal of federal clean energy legislation and regulations after 2025, but maintains the state-level policies under *Current Policies.* Policies that are rolled back are assumed to be repealed after 2025 and with few exceptions are rolled back completely. In reality, policies may not be rolled back completely or they may be replaced with weaker policies. Additionally, we assume that the federal government does not limit the ability of states to enact and implement climate policies. Under this assumption, the state of California continues to receive its waiver for clean air programs, and other states are able to adopt California's regulations. A repeal of the California waiver would complicate the ability of subnational governments to enact ambitious emissions reductions policies

Details for federal climate ambition assumptions in each of these scenarios are described in section 3. Detailed assumptions for non-federal climate actions included in our scenarios are shown in section 4.

## 3. Federal Assumptions

| Policy type | Policy | Current Policies | Federal Rollbacks |
|---|---|---|---|
| **Federal legislation** | IRA | Maintained, expires as written | Repealed after 2025 |
| | BIL | Maintained | Repealed after 2025 |
| | AIM Act | Maintained | Repealed after 2025 |
| **Federal regulations** | Regulations for new gas and coal generation | Maintained | Repealed after 2025 |
| | CAFE standards and GHG standards for LDVs | Maintained | Repealed after 2025 |
| | Oil and gas methane regulations | Maintained | Repealed after 2025 |
| | GHG emissions standards for freight trucks | Maintained | Repealed after 2025 |

**Table S1.** Modeled federal policies across a range of federal ambitions. For detailed descriptions about how specific policies were modeled in GCAM-USA-CGS, see our previous analysis here.

## 4. Non-Federal Assumptions

| Sector | Policy | *Current Policies* and *Federal Rollbacks* scenarios |
|---|---|---|
| Electricity | Renewable Portfolio Standards | Current state-level RPS targets are modeled. |
| Electricity | Cap and trade | The Regional Greenhouse Gas Initiative (RGGI) is modeled as a 30% reduction in power sector emissions below 2020 levels by 2030 in participating states. |
| Transportation | LDV sales targets | California and the 14 other states that have adopted ZEV sales targets consistent with California's Advanced Clean Cars (ACC) II legislation are assumed to achieve their passenger car sales target of 68% electric in 2030 and 100% in 2035. Additionally, the 2 states that have only adopted legislation consistent with California's ACC I legislation are modeled to have ZEV sales reach 22% in 2025. |
| | LDV EV incentives | Major existing incentives for LDV ZEVs at the state-, utility-, and district levels from the Alternative Fuels Data Center are modeled at the state level as reductions in per-vehicle capital cost. Altogether, these are equivalent to a national average capital cost reduction for LDV EVs of $826 per vehicle. |
| | M/HDV sales targets | California and 11 other states achieve sales targets for electric trucks by 2035 consistent with California's Advanced Clean Trucks legislation. |
| Buildings | Energy efficiency | Current state-level energy efficiency resource standards were modeled by reducing state-level building service demands. |

**Table S2.** Existing non-federal climate actions assumed in both modeled scenarios. For comparison, assumptions under the *Current Policies* scenario from our earlier report are provided. For detailed descriptions about how specific policies were modeled in GCAM-USA-CGS, see here.

## 5. GCAM-USA-CGS

Our analysis uses a version of the open-source Global Change Analysis Model (GCAM) to estimate the aggregate impact of federal and non-federal climate policies and actions on economy-wide emissions reductions in the United States. Specifically, we use GCAM-USA, a state-level version of GCAM. We refer to the version of GCAM-USA used in this study as GCAM-USA-CGS.

GCAM is an integrated assessment model (IAM) of the energy, land, water, climate, and socioeconomic systems. The global version of GCAM groups the world's countries into 32 geopolitical regions with representation of the energy and socioeconomic systems for each region. The United States is one of the 32 regions. GCAM represents the global climate system, and uses 235 water basins and 384 land regions to represent global water and land systems. GCAM tracks emissions and sinks of carbon dioxide ($CO_2$), 16 other GHGs, and several air pollutants.

The state-level version of GCAM used in this analysis, GCAM-USA, disaggregates the U.S. energy and economy components into 50 states and the District of Columbia while maintaining the same level of detail as GCAM for water and land sectors. The energy system in GCAM-USA has representation of depletable primary energy sources including coal, gas, oil, and uranium, in addition to renewable resources including biomass, hydropower, solar, wind, and geothermal. Energy transformation processes like oil refining and electricity generation are represented at the state-level in GCAM-USA. These energy carriers, in turn, are used to deliver services to state-level end users in the buildings, transportation, and industrial sectors. The electric power sector includes representation of a range of electricity generation technologies, including those fueled by fossil fuels and bioenergy (with and without CCS), renewables, and nuclear.

GCAM-USA is a market equilibrium model. The model solves for equilibrium in each period by finding a set of market prices such that supplies and demands are equal to one another in all markets as model actors adjust the quantities of the commodities they demand and supply. GCAM operates in 5-year time-increments, with each new period starting from the conditions that emerged in the previous period, and with most technologies being vintaged such that a portion of existing stocks in each period carry over into future time periods.

GCAM-USA-CGS is based on the open-source release of GCAM-USA 6.0.[1] GCAM-USA-CGS has been updated for the purposes of this study to reflect changes such as the most recent estimates of future renewable energy costs and non-$CO_2$ marginal abatement costs.

## 6. InMAP and BenMap

To evaluate air pollution levels and related health impacts across the U.S., we combine projections from GCAM-USA-CGS with a reduced-complexity air quality model (Intervention Model for Air Pollution, InMAP) and a health impact assessment tool (EPA's Environmental Benefits Mapping and Analysis Program – Community Edition, BenMAP-CE). This modeling framework is consistent with approaches used in our previous studies.

First, we spatially downscale state-level emissions from GCAM-USA-CGS to a 12 km × 12 km grid using proportional factors derived from 2017 emissions patterns. These patterns are taken from the National Emissions Inventory (NEI) for sectors such as power, transportation, industry, and buildings sectors. We assume that these spatial patterns remain constant from 2015 to 2035. For emissions outside the contiguous U.S., such as Canada and Mexico, we hold values constant at 2017 levels to isolate the effects of domestic changes. This alternative approach reveals that while overall pollution patterns remain similar, localized hotspots can differ, highlighting the importance of spatial resolution in identifying pollution disparities.

We then use InMAP, a reduced-complexity air quality model, to simulate annual average concentrations of fine particulate matter (PM2.5). InMAP models both direct emissions and secondary formation of PM2.5 (including sulfate, nitrate, and ammonium) from precursors such as $SO_2$, $NO_x$, $NH_3$, VOCs, and primary PM2.5. The model uses a steady-state version of the atmospheric transport and chemistry equations, representing the effects of wind transport, atmospheric mixing, and chemical transformations. Meteorological inputs are derived from WRF-Chem simulations for the year 2005. InMAP runs at variable spatial resolutions from

1 km in urban areas to 48 km in rural regions and includes 29 vertical layers, with the lowest layer representing near-surface concentrations. While InMAP simplifies some physical and chemical processes, it has been validated for its ability to capture large-scale pollution trends and is frequently used in energy and climate policy research due to its efficiency.

To estimate health impacts, we input the PM2.5 concentrations from InMAP into BenMAP-CE (v1.5.8), a U.S. EPA-developed tool that quantifies health effects from changes in air pollution. We estimate county-level exposure using population-weighted averages when multiple InMAP grid cells overlap a county, and assign uniform concentrations when grid cells are larger than county boundaries. Our primary health outcome is premature mortality from long-term PM2.5 exposure, calculated using the log-linear exposure-response function from  Krewski et al. These health assessments assume fixed population demographics and baseline mortality rates over time. While this limits the model's ability to account for future demographic changes or behavioral adaptation, it allows for consistent, comparative evaluation of policy-driven air quality changes.

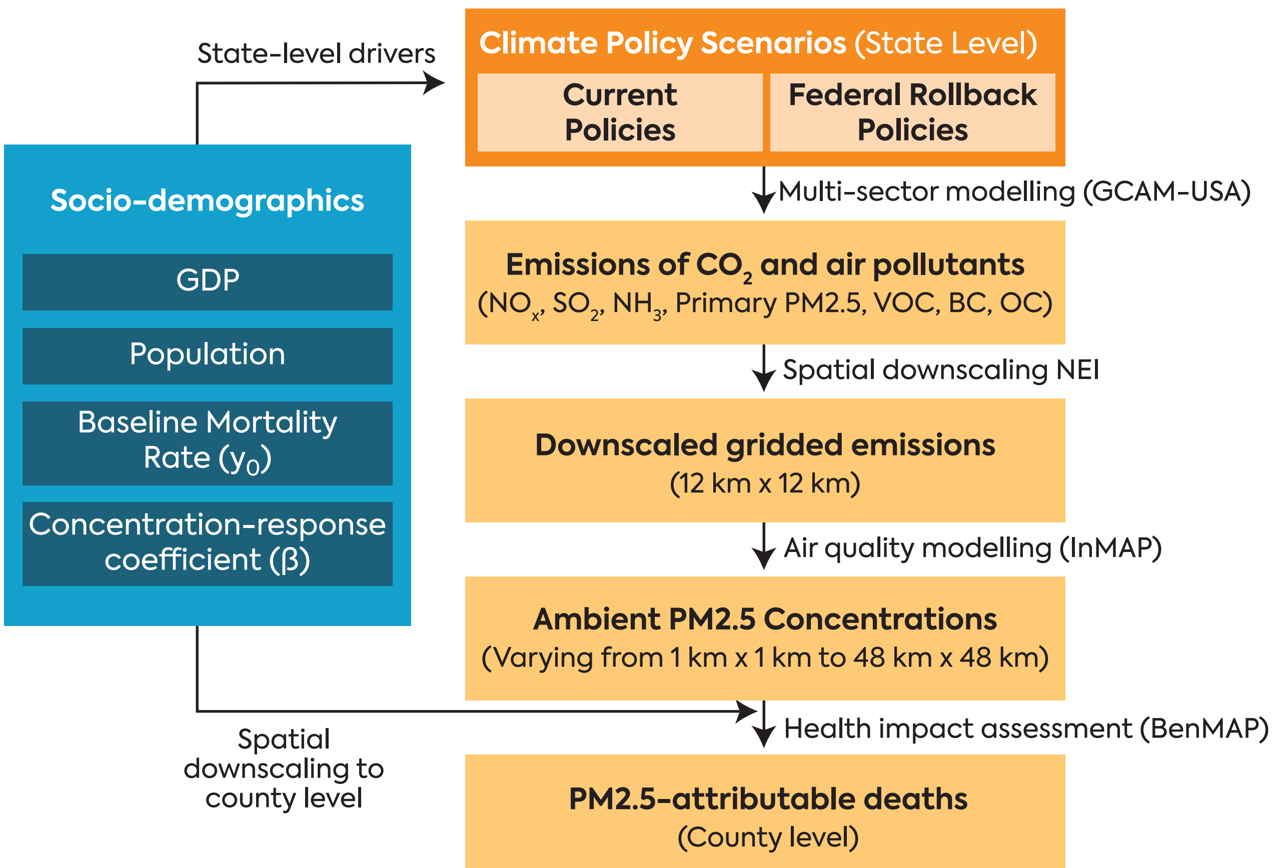


**Figure 1.** Integrated modeling methods used in this report.

# 7. IMPLAN

The IMPLAN (Impact Analysis for Planning) input-output model provides detailed information on the spatial distribution and the input structure (technology) of various sectors.[2] Furthermore, using the Leontief inverse matrix, the IMPLAN model can capture inter-regional industrial linkages and trade flow, thereby enabling the quantification of both direct and upstream supply chain impacts of the energy transition on GDP and labor income across regions.

To incorporate the GDP and labor income effects of the energy transition under both scenarios, we match 14 sectors in GCAM-USA-CGS (mainly electricity generation and end use sectors of natural gas, refined liquids, coal, and biomass) to the 11 energy sectors in IMPLAN. When matching the results from GCAM-USA to the IMPLAN model, the units of the energy production in the two models are different. The energy consumption in GCAM-USA-CGS is measured in physical units (EJ), while that in IMPLAN is measured in monetary units (2020$). To address this discrepancy, we used the growth rate for each type of energy derived from the projection in GCAM-USA-CGS to scale up the electricity output by technology in IMPLAN. For example, if the electricity generated by biomass in GCAM-USA-CGS grows by 50% in 2035 compared to 2020, then the output for the *Electric power generation – Biomass sector* in IMPLAN would be assumed to also grow by 50%.

Once we match the output changes of those sectors in IMPLAN, we can use a Leontief inverse matrix to trace the GDP, and labor income effect of the energy transition.[3] The formula as follows:

$$E = f(I - A)^{-1}\Delta X$$

Where E represents the value added/labor income impacts. $f$ represents the value added/income intensity vector, which is the value added/labor compensation generated by 1$ output in each sector. $(I - A)^{-1}$ is the Leontief inverse matrix, in which is an identity diagonal matrix and is the direct consumption coefficient matrix (a description of input structure for each sector), which reflects all direct and indirect intersectoral input-output linkages. $\Delta X$ denotes the changes in output for all energy sectors (*Federal Rollbacks - Current Policies*).

It is important to note that our approach does not cover the impacts associated with transition occurring in the end uses on the demand side, for example, electric vehicle battery manufacturing and infrastructure in transport or heat pump manufacturing and installation in buildings. Therefore, we likely underestimate the overall economic effects under *Federal Rollbacks*. Moreover, GCAM and IMPLAN use different sectoral classifications, which introduces additional uncertainties.

[2] MIG, Inc. (2002) Elements of the Social Accounting Matrix. MIG IMPLAN Technical Report TR-98002.
[3] Wang, D., Guan, D., Zhu, S., Kinnon, M. M., Geng, G., Zhang, Q., ... & Davis, S. J. (2021). Economic footprint of California wildfires in 2018. Nature Sustainability, 4(3), 252-260.