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Meeting Potential New U.S. Climate Goals

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MIT Joint Program on the Science and Policy of Global Change combines cutting-edge scientific research with independent policy analysis to provide a solid foundation for the public and private decisions needed to mitigate and adapt to unavoidable global environmental changes. Being data-driven, the Joint Program uses extensive Earth system and economic data and models to produce quantitative analysis and predictions of the risks of climate change and the challenges of limiting human influence on the environment—essential knowledge for the international dialogue toward a global response to climate change.

To this end, the Joint Program brings together an interdisciplinary group from two established MIT research centers: the **Center for Global Change Science (CGCS)** and the **Center for Energy and Environmental Policy Research (CEEPR)**. These two centers—along with collaborators from the Marine Biology Laboratory (MBL) at Woods Hole and short- and long-term visitors—provide the united vision needed to solve global challenges.

At the heart of much of the program's work lies MIT's Integrated Global System Model. Through this integrated model, the program seeks to discover new interactions among natural and human climate system components; objectively assess uncertainty in economic and climate projections; critically and quantitatively analyze environmental management and policy proposals; understand complex connections among the many forces that will shape our future; and improve methods to model, monitor and verify greenhouse gas emissions and climatic impacts.

This report is intended to communicate research results and improve public understanding of global environment and energy challenges, thereby contributing to informed debate about climate change and the economic and social implications of policy alternatives.

—***Ronald G. Prinn,***
Joint Program Director

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Meeting Potential New U.S. Climate Goals

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Abstract: We explore the performance of a potential addition to U.S. climate policy using authority under Section 115 of the Clean Air Act, with special attention to distributional effects among the states. This portion of the Act concerns trans-boundary air pollution, and under its provisions a national greenhouse target could be allocated among the states, with the details of state implementation optionally guided by a model rule as under other provisions of the Act. With trading allowed among the states, such a measure could lead to a national price on the covered gases. While we adopt features of a possible Section 115 implementation, the illustrative analysis is applicable to similar cap-and-trade programs that might be adopted under other authorities. We investigate the implications of such a policy using MIT's U.S. Regional Energy Policy (USREP) model, with its electric sector replaced by the Renewable Energy Development System (ReEDS) model developed by the U.S. National Renewable Energy Laboratory. Existing federal and state climate policies are assumed to remain in place, and a national constraint on CO_2 emissions is applied to achieve 45% or 50% reductions below the 2005 level by 2030. We apply the policies in a Baseline and a Low-Cost Baseline, the latter with more aggressive assumptions of technology cost improvements. The U.S. is aggregated to 18 individual states and 12 multi-state regions, and the effects of the national emissions restriction are investigated under three alternative methods by which the EPA might allocate these targets among the states. We find the cost of achieving either target to be modest - allowing for nearly identical economic growth, even without taking account of air quality and climate benefits. The alternative allocation methods generate varying per capita revenue outcomes among states and regions and drive most of the welfare impact through a direct income effect. It is assumed that states distribute permit revenue to their residents in equal lump-sum payments, which leads to net benefits to lower income households. Under the Low-Cost Baseline, carbon prices in 2030 are about ⅓ those in the Baseline, and the overall pre-benefit welfare effects are negligible. Considering climate benefits evaluated using the social cost of carbon and particulate matter air pollution health benefits, less the mitigation costs, we find net benefits in all cases, with slightly larger net benefits with the 50% reduction below 2005 emissions.

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1. A Potential U.S. National GHG Emissions Policy

1.1 Action Under the Clean Air Act

To make its contribution to the Paris Agreement goal of keeping global warming "well below" 2°C, the U.S. will need to reduce its greenhouse gas emissions sharply over the next few decades. Though states, cities and many in the private sector are taking action on their emissions, federal leadership is needed, preferably pursuant to new comprehensive climate legislation. However, since 2009 when a comprehensive climate bill cleared the House but failed in the Senate, the U.S. Congress has not seriously considered legislation that could achieve the needed emissions reductions. Even with growing public support for national action on climate, congressional passage of comprehensive climate legislation also seems unlikely in the near future. Fortunately, an alternative response is available to meet the climate challenge: executive action, including under the Clean Air Act (CAA).

Previously, the Obama Administration launched a Climate Action Plan whose centerpiece was action under the CAA. It applied CAA Section 202(a), which grants the U.S. Environmental Protection Agency (EPA) the authority to regulate emissions from new motor vehicles, and Section 111, which does the same for new and existing stationary sources (used to set standards for power plants, landfills, and oil and gas operations). Though the resulting regulations were subsequently weakened by the Trump Administration, these CAA provisions are important tools for emissions control. Yet they are also imperfect mechanisms for achieving ambitious, comprehensive GHG emissions control. This sectoral approach makes key sources of emissions, such as vehicles already on the road, difficult to address. Also, the constraints within each section of the statute (e.g., the directive to use the "Best System of Emissions Reduction" under Section 111) could limit the potential reductions. Further, the sector-by-sector approach not only reduces the speed of reductions, by requiring multiple time-consuming rulemakings, but can also miss potential economic efficiencies by limiting the ability to seek the lowest-cost emission reductions regardless of source or location, and it opens up potential leakage to under- or uncontrolled sectors.

One possible outcome of this sector-by-sector approach under existing authority is a gap between what the sector-by-sector approach can achieve and the emissions reductions needed to put the U.S. on track to meeting the Administration's long-term emissions goals or even potential new emissions pledges under the Paris Agreement. For example, one prediction of baseline emissions in 2030 is that total U.S. GHG emissions might be 27% below 2005 levels. (Larsen *et al.*, 2020). Conventional regulatory policies could further reduce emissions. But because of constraints on these measures, the failure to address all emission sources, and the possibility of leakage and rebound effects, reductions could fall short of the desired level.[1]

Seeking an approach to close any potential 2030 emissions gap, we explore another policy tool provided in the CAA: Section 115 which concerns international air pollution. This provision of the Act offers a possible opportunity to fill the gaps among state and federal policies, avoiding limitations of actions under Sections 202(a) and 111, and to do so in an efficient, flexible, and equitable fashion. Potential designs for such a policy are investigated using a simulation model of the U.S. economy, with particular attention to the distribution of economic impacts among the states, and among income groups within states.

1.2 Features of CAA Section 115

Section 115 (42 U.S. Code § 7415) on "International Air Pollution" has been part of the Clean Air Act since 1965. It is triggered when:

a) EPA ". . . has reason to believe that any air pollutant or pollutants emitted in the United States cause or contribute to air pollution which may reasonably be anticipated to endanger public health or welfare in a foreign country" (endangerment), and

b) that the other country "has given the U.S. essentially the same rights with respect to the prevention or control of air pollution occurring in that country as is given that country" (reciprocity).

This provision of the CAA is potentially well suited for application to climate policy considering the danger of climate change to the U.S., the transboundary nature of greenhouse gases, and the reciprocity provided by the Paris Agreement, wherein all emitters have pledged emissions reductions. When the two conditions above are met, EPA must require each U.S. state to develop an implementation plan through the same process used for implementing the National Ambient Air Quality Standards (NAAQS), which provides flexibility to adopt a range of tools (e.g., fees, permits, auctions) that can build upon existing efforts in those states. Also, unlike sector specific EPA regulatory authorities for climate, Section 115 allows the EPA to address the totality of GHG emissions (Burger, 2020).

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[1] For an example, consider the avenues of leakage in a sector-by-sector regulatory approach that includes aggressive standards for new light and heavy duty vehicles, an updated 111(d) standard for the electricity sector, and updated energy efficiency standards. Higher costs of new vehicles could create an incentive to keep old inefficient vehicles in service longer, or a higher commercial electricity price might encourage industry to self-generate power. Rebound effects can involve people driving more or turning the thermostat higher because with greater efficiency the fuel cost is lower.

Section 115 would be implemented following the traditional U.S. mode of cooperative federalism. In this framework, the EPA sets national environmental targets, imposes constraints or other conditions on the states, may promulgate a model rule to help states design efficient and effective approaches, and leaves it to each state to develop and carry out a State Implementation Plan (SIP) suited to its particular circumstances. For climate in particular, states that already have ambitious climate programs (e.g., California, New York, Colorado) may find that their existing policies are largely adequate to serve as the state implementation plan. Other federal policies, such as vehicle standards under CAA Section 202, can assist states in meeting their individual obligations.

More specifically, under Section 115 the EPA could set a target for total U.S greenhouse gas emissions and allocate the required reductions to the states in some manner. The SIP process would leave each state free to adopt its own policies to meet its allocated share, including the ability to trade allowances with other states. Consistent with other recent policies, such as the Cross State Air Pollution Rule (CSAPR), EPA could issue a model rule to provide states with a uniform trading framework. While states would be free to adopt other approaches to meet their goals, under CSAPR 100% of states adopted the model rule and participated in a trading program. Each state would maintain discretion about how to distribute the allowances, or revenue from allowance auctions.

If we assume that all states would participate in national trading, one result would be a national allowance price for the covered emissions. Such a policy would, however, have different effects among the states depending on how the emissions reduction obligations were allocated and on the structure of a state's economy, particularly its energy sector.

The U.S. Supreme Court has offered deference to EPA in determining how to distribute emission reduction obligations among the states. In its ruling on EPA vs. EME Homer City, the Court laid out three approaches by which such an allocation could be made (Barnett and Teitz, 2020). One would allocate emissions to equalize marginal compliance costs across the states (as EPA did in the Cross-State Air Pollution Rule). A second would allocate in proportion to a baseline emissions level, and a third would be on a per capita basis. Other allocations, or combinations of approaches are possible, but we use these three approaches to illustrate how EPA's allocation choices might be used to balance regional considerations.

2. Analysis Method

We explore the implications of a potential national climate policy under CAA Section 115 using a state/regional-level model of the U.S. economy, augmented by a detailed model of the electric sector. The effects of the three methods for allocating emissions are considered under two potential national policy targets: a reduction in national CO_2 emissions of 45% and 50% below the 2005 level by 2030. These targets span a range of near-term emissions reductions consistent with a straight-line path to the 2050 net zero emissions goal laid out by the Biden-Harris Administration. While states have considerable flexibility under Section 115, to facilitate our modeling we assume that states would elect to implement Section 115 by participating in a market-based allowance system.

2.1 The Combined USREP-ReEDS Model

The analysis employs an updated version of the U.S. Regional Energy Policy (USREP) model (Yuan *et al.*, 2019), with elaboration of its electric power sector by linkage to the Renewable Energy Deployment System (ReEDS) model developed by the U.S. National Renewable Energy Laboratory (Brown *et al.*, 2020). The two model components and their integration can be summarized as follows.

2.1.1 The USREP Component

Production sectors and households in USREP are modeled with Constant Elasticity of Substitution (CES) production and consumption functions, in some cases adding explicit representation of new technologies such as electric vehicles. Elasticities of substitution determine how producers and consumers change their consumption of fuels and electricity in response to relative prices. An emissions cap under Section 115 induces reductions in emissions by passing carbon prices through fuel prices in proportion to the carbon emitted by each fuel type, leading all sectors of the economy and households to reduce fuel use to avoid this extra cost. Any additional costs of producing goods are further passed on through the price of the goods, offering an additional incentive to reduce emissions.

To explore sub-national effects of Section 115 implementation, the version of USREP applied in the analysis distinguishes 30 U.S. regions, including 18 individual states and 12 multi-state regions (**Figure 1**). To assess distributional effects of the policy, each region in USREP includes representative households for each of nine income levels (later aggregated to quintiles for graphical presentation). Household income effects occur through several channels, including changes in prices of goods and services, effects on wages and capital returns, and by the way allowances, or the revenue from allowance sales, are distributed. In the results below, the distribution of allowance revenue often dominates the other impacts on household income.

The economic data for the USREP model are from the Minnesota IMPLAN group, and the physical flows of energy are taken from the U.S. Energy Information Agency's State Energy Data System. The sources of data for these and other aspects of the economy are listed in **Table 1**. (Details of the electric sector are provided with the ReEDS component.)

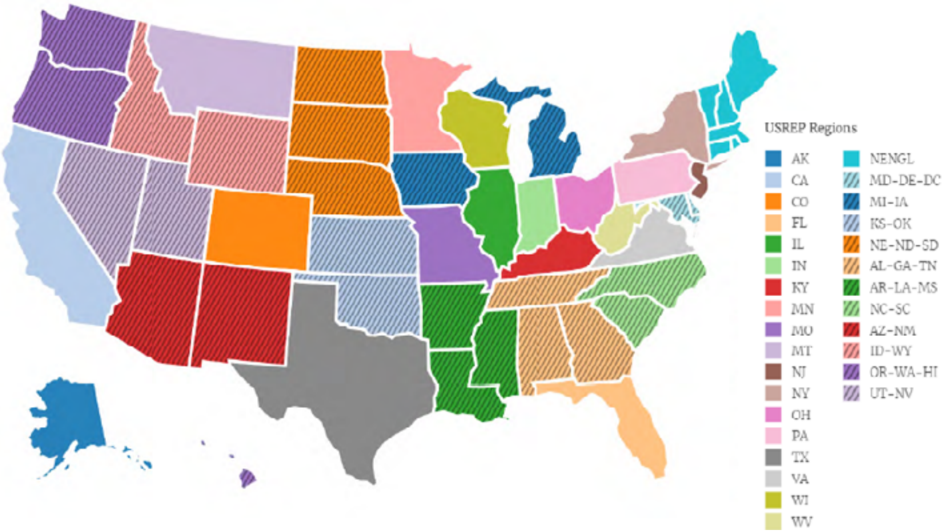

Figure 1. USREP Model, 30-Region Version

The U.S. is modeled as 18 individual states and 12 multi-state regions.

Table 1. Data Sources for the USREP Model

DATA AND PARAMETERS	SOURCE
Social Accounting Matrices	Minnesota IMPLAN Group (IMPLAN, 2008)
Physical Energy Flows and Energy Prices	Energy Information Administration - State Energy Data System (EIA-SEDS, 2009)
Fossil Fuel Reserves and Biomass Supply	U.S. Geological Survey (USGS, 2009) U.S. Department of Energy (DOE, 2009) Dyni (2006) Oakridge National Laboratories (ORNL, 2009)
Population Projection	U. of Virginia Demographics Research Group (UVA, 2018)
High-Resolution Wind Data	National Renewable Energy Laboratory - Wind Integration Datasets (NREL, 2010)
Non-CO_2 GHG Inventories and Endogenous Costing	U.S. Environmental Protection Agency (EPA, 2009) Hyman *et al.* (2002)
Marginal Personal Income Tax Rates	NBER's TAXSIM model (Feenberg and Coutts, 1993)
Trade Elasticities	The GTAP 7 Data Base (Narayana and Walmsley, 2008) and own calculation
Energy Demand and Supply Elasticities	MIT EPPA model (Paltsev *et al.*, 2005; Chen *et al.*, 2014)
Passenger Vehicle Transportation	Federal Highway Administration (FHWA, 2005) Davis and Boundy (2019)

2.1.2 The ReEDS Component

To more adequately capture the expected growing role of renewables under climate policy, the USREP representation of the electric sector for the continental United States is replaced by the ReEDS model developed by the U.S. National Renewable Energy Laboratory (NREL).[2] ReEDS considers 134 electricity balancing regions (**Figure 2**) and associated bulk transmission. These balancing regions are then further subdivided into 356 renewable-supply regions to capture details of potential wind and solar resources.

The ReEDS model includes a comprehensive set of conventional generation sources as well as renewable technologies, and a range of storage options (**Table 2**). The model captures variation in power supply and demand over the load day and the course of the year by identifying 17 separate loads, comprised of four representative diurnal time periods (morning, afternoon, evening and night) for each season (winter, spring, summer, fall) and a super peak which represents the highest 40 hours of load in a year. This approach provides an ability to assess the value of intermittent renewable resources, such as wind and solar, taking account of the way further additions to such supplies in particular regions will match seasonal and weekly patterns of demand.

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[2] For the non-continental US we retain the USREP representation of the electricity sector, including multiple vintaged generation technologies with a simpler supply curve representation of graded renewable resources.

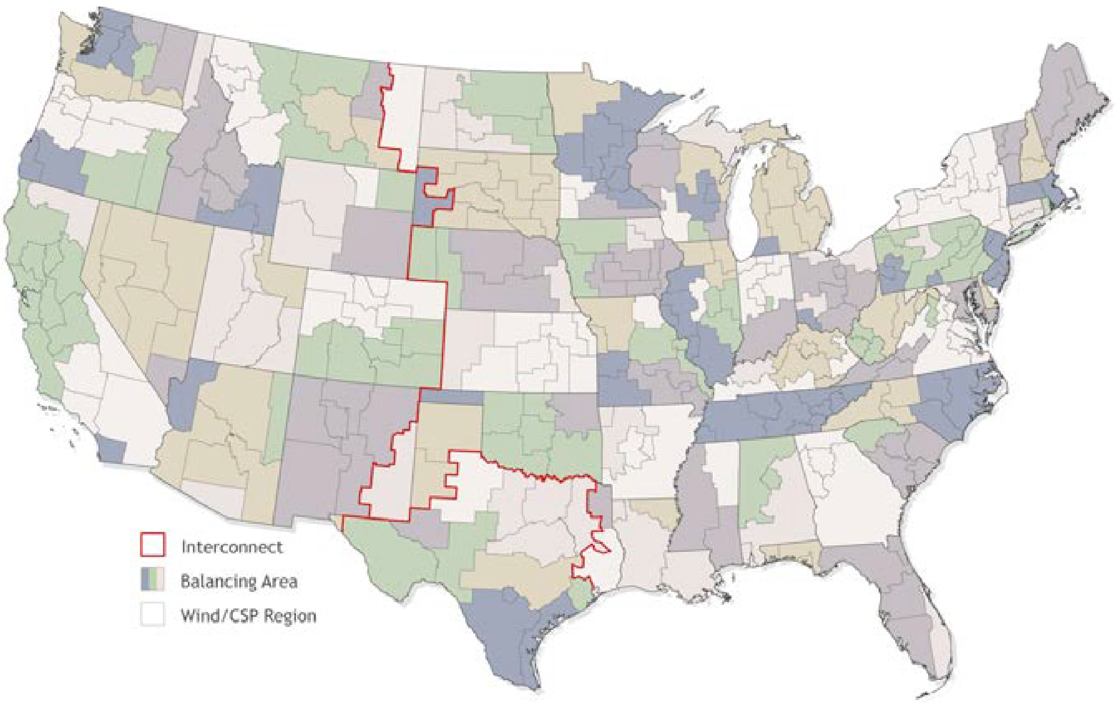

Figure 2. Regional Structure of the ReEDS Model

The ReEDS model includes 134 balancing areas and distinguishes 356 regions of renewable supply.

Table 2. Electric Supply Technologies in the ReEDS Model

ReEDS TECHNOLOGY DESCRIPTIONS		
Conventional Generating Technologies	**Coal**	Traditional pulverized coal with and without SO_2 scrubbers
		Integrated gasification combined cycle (IGCC) with or without CCS (Coal-CCS)
		Co-fired coal with biomass
	Natural Gas	Combustion turbine (Gas-CT)
		Combined cycle (Gas-CC)
		Combined cycle with carbon capture and sequestration (Gas-CCS)
	Nuclear	
	Oil-Gas-Steam	
	Landfill Gas	
Renewable Generating Technologies	**Land-Based Wind**	
	Offshore Wind	
	Solar Photovoltaics (PV)	
	Concentrating Solar Power (CSP)	
	Geothermal	
	Hydropower	
	Biopower	
	Marine Hydrokinetic Wave	
Storage Technologies	**Pumped hydropower storage (PHS)**	
	Batteries	
	Compressed air energy storage (CAES)	
	Thermal storage in buildings	

2.1.3 Inter-Model Linkage

An earlier version of the linked USREP-ReEDS model is described in Rausch and Mowers (2012). The analysis framework applied here follows that approach, linking the two models using a decomposition algorithm that exploits the block-diagonal structure of the Jacobian matrix of the problem, initially demonstrated by Böhringer and Rutherford (2009). USREP represents electricity demand and fuel demand outside the electricity sector, as well as fuel supply. ReEDS represents electricity supply, fuel demand, capacity investment, operating expenditure and inter-state trade for the power sector. The solution algorithm iterates to clear markets consistently in the two models. The markets for fuels and electricity have the strongest links, but it is also crucial to consistently clear capital and labor markets, and a market for carbon allowances. The models are solved recursively on a five-year time step to provide a quantitative description of the evolution of the U.S. economy and its energy sector, with and without potential Section 115 implementation.

2.2 Policy and Economic Assumptions

Emissions control measures under Section 115 would be implemented in the context of federal and state policies already in place and economies affected by the Covid-19 pandemic and gradual recovery from the recession. As summarized in **Table 3**, the analysis baselines include the effects of emissions control measures already in place or firmly committed, as well as updated prospects for economic growth including an approximation of the effects of COVID-19.

Our focus is on results through 2030. A regulatory program of this scope likely would be significantly updated after five to ten years (or replaced with legislation), and model uncertainties are too large to make quantitative results useful for detailed policy design outside this time window (Barron *et al.*, 2018).

Creating baselines for the analysis is a 3-step process as outlined in Table 3. First, we prepare a Reference projection calibrated to historical data and EIA's annual energy outlook. Then, in a second step we adjust this Reference projection for more recent developments (the pandemic, additional state and regional policies) with technology cost and efficiency assumptions, including NREL's 2019 Mid Range technology cost assumptions, to create a Baseline. In Table 3 and discussion below this is referred to as the Mid Range Baseline. In the third step we adjust this result to create what we term a Low Cost Baseline by imposing a lower-cost projection of electric sector costs from NREL and more optimistic assumptions about other sectors. Policy scenarios are developed and compared against these two baselines.

2.2.1 Reference Economic and Energy Projections

The base-year of the model is 2006, and simulated historical state and regional economic activity is calibrated to more

Table 3. Reference, Baseline and Policy Scenarios

LABEL	SCENARIO DESCRIPTION	
AEO Reference	• Regional economic growth is calibrated to BEA GSP for the historical years • Future U.S. economic growth is calibrated to AEO 2020 reference projection • Regional electricity load grows at the same rate as AEO 2020 electricity supply	• Uses NREL's ATB 2019 Mid-Range Electricity technology cost and performance assumption • ReEDS reference case assumption on RPS, CES and wind/solar carveout by state • AEO 2020 CAFE standards for Light Duty Vehicles, with LDV costs based on a review by Ghandi and Paltsev (2019).
Mid-Range Baseline	• Electricity technology cost and performance assumptions remain as in the Reference, including NREL's 2019 "Mid-Range" ATB cost and performance assumptions • COVID-19 pandemic effect implemented as an impact on the labor force	• Regional abatement policies (AB32 Tax in CA*, emissions cap in CO and NY) • Policy updates in RPS/CES and wind/solar carveouts • Updated RGGI cap with VA's participation starting in 2025 • Government revenue neutrality is maintained through personal income tax adjustment
Low-Cost Baseline	• Uses NREL's 2019 "Low" ATB cost and performance assumptions • Assumes 3% per year annual energy efficiency improvement in all states/regions similar to CA's annual rate in recent decades.	• Assumes electric vehicle cost parity with ICE vehicle cost after 2025. The ICCT (Lutsey and Nicholas, 2019) and Bloomberg New Energy Finance (2020) project parity by the mid-2020's.
Policy Scenarios	• A national cap on fossil-fuel derived CO_2 is set relative to the 2005 emissions • The national cap starts in 2025 with a 30% reduction target, and achieves overall 45% or 50% reductions below the 2005 level by 2030 • Regional emissions control measures and targets in the Baseline remain in place	• State shares of emissions reductions are generated based on three allocation rules, Equal Per Capita (EPC), Equal Marginal Cost (EMC), or Equal Cut from Baseyear (ECB) • State allowance revenue derived from auctioning of allowances is allocated on a per capita basis to each state's residents.

* The Agriculture and Other sectors are exempted from AB32's cap and trade program. In order to better capture the impacts of AB32 on power imports, the AB32 cap implemented in the AEO Reference case is replaced with a tax on the emissions.

recent data for Gross State Product from the U.S. Bureau of Economic Analysis (BEA, 2020). The Reference Scenario of future economic activity is based on a projection of economic growth and energy use through 2030. Projected state economic and electricity demand growth is calibrated so that national GDP and electricity demand growth matches that of the U.S. Energy Information Administration's Annual Energy Outlook 2020 Reference Case (AEO, 2020). The associated levels of gross product vary over time due to differences among states in population growth, industry mix and resource endowment. The ReEDS model includes NREL's Mid Range technology cost assumptions (NREL, 2019), and reference assumptions for state level Renewable Portfolio Standards (RPS) and Clean Energy Standards (CES), including various carve-outs for wind and solar generation. Light-duty vehicle (LDV) costs are based on a review by Ghandi and Paltsev (2019), and (consistent with the AEO 2020) Obama-era CAFE standards for LDVs are included.[3]

2.2.2 Economic and Energy Baselines

Starting with the Reference Scenario, we make adjustments to reflect the economic effects of the COVID-19 pandemic, which occurred after the AEO estimate was made, and newly adopted State policies. With estimates of the GDP loss caused by the pandemic in 2020, and recovery in subsequent quarters, we project the path by which economies may return to full employment over the longer term (Reilly, Chen and Jacoby, 2021). The longer-term economic impact of the pandemic will, of course, depend on the progress of the virus and pace of vaccine development and use, and on the fate of additional fiscal measures to promote recovery from the downturn. Thus, our estimate is a simplified extrapolation of just one possible path of the pandemic's initial economic impact and recovery, and much uncertainty remains. Still, given the significance of the pandemic, some accounting for its effects on the economy, energy use and emissions is necessary. Compared to the AEO Reference, the COVID-only impact is a 2.2% reduction in GDP and a 1.7% reduction in emissions in 2030.

Normally, calibration to the most recent EIA reference (AEO, 2020), adjusted for pandemic effects, would provide a good baseline from which to assess the implications of an additional policy initiative. However, a number of states have adopted new or additional policies aimed at reducing greenhouse gas emissions that are not reflected in the EIA reference, so we incorporate other refinements that will influence estimates of the economic effects of additional measures. We approximate application of the AB32 cap on emissions in California, and represent the mandatory emissions goals adopted in Colorado and New York as emissions caps implemented through market programs. Assumed revenue from the state programs is retained within the relevant state and allocated to state residents on a per capita basis. We represent the RPS/CES standards currently enacted/in place at the state level (Appendix A), adjusted for the share of electricity generation not covered by the policy. This last group includes an RPS in Virginia enacted in 2020. Economy-wide targets for Connecticut, Maryland, Hawaii, Minnesota, Vermont, Nevada and Virginia were not included because they were either non-binding or they required additional legislation to ensure the targets are met. (To the extent that these states adopt implementing legislation in the next few years, costs attributable to a Section 115 program could be lower than estimated here, depending on how the state measures are integrated with the federal policy.)

These policy measures included in the baseline remain in place through the policy scenarios. Compared to the AEO Reference, our Baseline U.S. emissions are lower by 1.5% in 2025 and 3.1% in 2030 under the Mid-Range cost assumption.

The Low-Cost Baseline includes adjustments discussed above and adopts NREL's 2019 ATB "Low" cost technology assumptions. (These are very similar to the newer 2020 ATB Mid-Range assumptions.) It assumes electric vehicle (EV) cost parity with internal combustion vehicles after 2025, consistent with other recent projections such as those by the ICCT (Lutsey and Nicholas, 2019) and Bloomberg New Energy Finance (2020). More ambitiously, it assumes all states/regions achieve a 3% annual energy efficiency improvement going forward, similar to the rate California has achieved in recent decades. That state has pursued energy efficiency policies more actively than others, so this assumption implies that other states or the federal government will adopt measures that encourage efficiency through new incentives, or that enforce efficiency through building codes or other regulations. The compounding effect of an increased rate of energy efficiency improvement has strong effects such that, compared to the AEO Reference with ATB Mid-Range costs, U.S. emissions are lower by 7.0% in 2025 and 14.9% in 2030 in the Low-Cost Baseline. In general, this baseline offers one sense of how declining technology costs and ambitious complementary policies can reduce emissions in the baseline.

2.3 Net Benefits Methodology

We estimate national net benefits in 2030 under Section 115 policies relative to the Mid-Range and Low-Cost Baselines. Net benefits are calculated as the sum of climate and particulate matter pollution health benefits less the direct

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[3] LDV standards were significantly weakened as the Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule by the Trump Administration, but are likely to be reinstated or tightened by the Biden Administration. California continues to pursue the more aggressive Obama-era stringencies.

welfare costs of mitigation. Climate benefits are estimated using a social cost of carbon of $59.50 per metric ton from the IWG (2016) reflecting a 3% discount rate. The $59.50 is the estimated social cost of carbon in 2030, inflated to 2018 dollars to make it comparable with welfare cost reporting.[4] Health benefits reflect reduced premature mortality from exposure to fine particulate matter ($PM_{2.5}$) and are estimated as follows. First, for each policy scenario, future emissions levels of primary $PM_{2.5}$, sulfur dioxide, nitrogen oxides, ammonia, and volatile organic compounds are projected by scaling detailed National Emissions Inventory (NEI) data (EPA, 2020) based on regional USREP-ReEDS outcomes; a more detailed description of this approach is documented in Dimanchev *et al.* (2019). [5] Next, concentrations of final $PM_{2.5}$ are estimated using InMAP, a reduced-form air quality model that simulates atmospheric chemistry and transport of pollutants (Tessum *et al.*, 2017); concentrations are interpolated to the county level for consistency with population and incidence data in the following step. Next, with county level population and mortality incidence rates,[6] we apply two concentration response functions reflecting associations between changes in exposure of $PM_{2.5}$ and premature mortality found in the literature: a "high" association (Lepeule *et al.*, 2012) and "low" association (Krewski *et al.*, 2009), yielding high and low net benefits; the former association is approximately 2.26 times higher than the latter. Lastly, health benefits are monetized using EPA's value of a statistical life (i.e. reduction in mortality risk) of $10.4 million in 2018 dollars for 2030, extrapolating the value from that reported for 2028 (EPA, 2018) by an estimate of per capita income growth between 2028 and 2030, times the reduced number of mortalities. The air pollution health benefits are only estimated for the continental U.S.

3. Implementation of Emissions Control Under Section 115

Based on past EPA program designs, we assume for this illustrative analysis that the EPA would issue a model rule that provides for state cap-and-trade programs with trading among states, and that all states would choose to adopt the model rule, resulting in a national trading program (although states would retain the flexibility to pursue alternate approaches, the ease of implementation and cost effectiveness of this approach is likely to be appealing). Each state's share of the required emissions reductions is translated into the corresponding quantity of emissions allowances that would be allocated to the state under a trading program.

In exploring the distributional consequences of the policy, we assume each state would distribute the allowance revenue to its residents on a per capita basis.[7] We assume a national market for allowances, so there will in all cases be a single national allowance price. We maintain revenue neutrality through increases in the personal income tax rate.[8]

We follow the Supreme Court ruling in EPA vs. EME Homer City as guidance for possible allocations among states.[9] Three possible approaches for distributing allowances among states include:

- Equal Marginal Cost (EMC). This approach aims to equalize the cost per ton of reduction in each state, even in the absence of allowance trading among states. The allocation is determined so that, if each state were to auction its allowances only within the state, the auction price would be identical across states, creating no opportunities for allowance arbitrage across regions. While it is possible to achieve this result exactly in the model simulation, an actual allocation would only approximate this outcome.
- Equal Cut from Base Year Emissions (ECB). Allowances are allocated to each state so that, if there were no trading, the response in each state would be an equal percentage (i.e., proportional) cut in emissions from its 2005 level. If the national target is a 50% cut in emissions from

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[4] The most recent estimate is $62 but the difference is due to accounting in 2020 dollars. See https://www.whitehouse.gov/omb/information-regulatory-affairs/regulatory-matters/#scghgs

[5] The underlying emissions are from NEI 2014, scaled to aggregate NEI 2017 levels to better capture recent and important emissions trends.

[6] County level population and all-cause mortality incidence rates are from EPA's COBRA model for the year 2025 (EPA, 2018a). Population is scaled to 2030 at the state level using state level projections using UVA (2018) (consistent with USREP welfare results); incidence is scaled to 2030 at the county level using all-cause incidence projections in EPA's BenMAP model (EPA, 2018b).

[7] While some states may choose to return all allowances on a per capita basis, others might use some portion of the funds to promote energy efficiency and clean energy, support trade-vulnerable industries, invest in disadvantaged communities, or other goals. For a summary of revenue use in carbon tax proposals see Hafstead (2020).

[8] Revenue neutrality assures that total tax collections and outlays, and the federal deficit, are unchanged as each policy scenario is compared with a baseline scenario. An increase in the deficit would create spending that was not balanced by tax collection, producing an apparent welfare windfall, failing to account for the potential deficit increase and its impact on future spending and/or taxes. Often the assumption is that carbon allowance revenue is retained to ensure neutrality, but under Section 115, states, not the federal government, would likely retain the revenue. Real-world revenue impacts of a Section 115 policy are challenging to predict and would depend upon shifts in markets and trade, induced innovation, and other factors.

[9] "Should the Agency allocate reductions proportionally (10 ppb each), on a per capita basis, on the basis of the cost of abatement, or by some other metric? The Good Neighbor Provision does not answer that question for EPA. ...Under Chevron, we read Congress' silence as a delegation of authority to EPA to select from among reasonable options."(EPA vs. EME Homer City 2014)

the 2005 emissions, then every state would be given allowances equal to 50% of its 2005 emissions.

- Equal Per Capita (EPC). Allowances are allocated to states based on population. If a state has 10% of the 2015 US population, it gets 10% of the allowances. As a result, equal per-capita revenue is realized by each state.

The choice of allocation method influences the distribution of burdens among states, as illustrated below. Under the EMC allocation, states with less expensive abatement options will receive relatively fewer allowances than states with more expensive ones. In the ECB approach, a state with high emissions per capita in 2005 would receive more allowances per capita than a state with lower emissions. The choice leads to different amounts of per capita revenue across states, and hence has varying effects on households across the country. The EPC allocation would ensure that if all states rebated revenue equally to all residents, the rebate would be equal across the country (another view of a fair allocation of revenue across states).

4. Analysis Results

4.1 Emissions prices and state reduction levels

By assumption, we specify the same intermediate target in 2025 in both the 45% and 50% reduction targets, resulting in identical national allowance prices in both scenarios of $14 (**Table 4**). The prices diverge in 2030. There are small differences in the allowance price across allocation approaches due to the income effect, but the differences are less than $1/MTCO$_2$. The Low-Cost Baseline allowance prices are one-half the Mid-Range 2025 levels, and are about one-third the 2030 prices. In the remaining sections of the main text, we focus on the Mid-Range Baseline. Figures and tables for the Low-Cost Baseline are reported in Appendix B.

Figure 3 shows the emissions reductions below 2005 levels, by state, for the two emissions targets. First considering the 45% target (light blue bars), the reductions in emissions

Table 4. Emission Price ($ 2018)

Baseline	% Reduction	Allowance Price ($/MTCO$_2$)	
		2025	2030
Mid-Range	45%	$14	$68
	50%	$14	$99
Low-Cost	45%	$7	$20
	50%	$7	$35

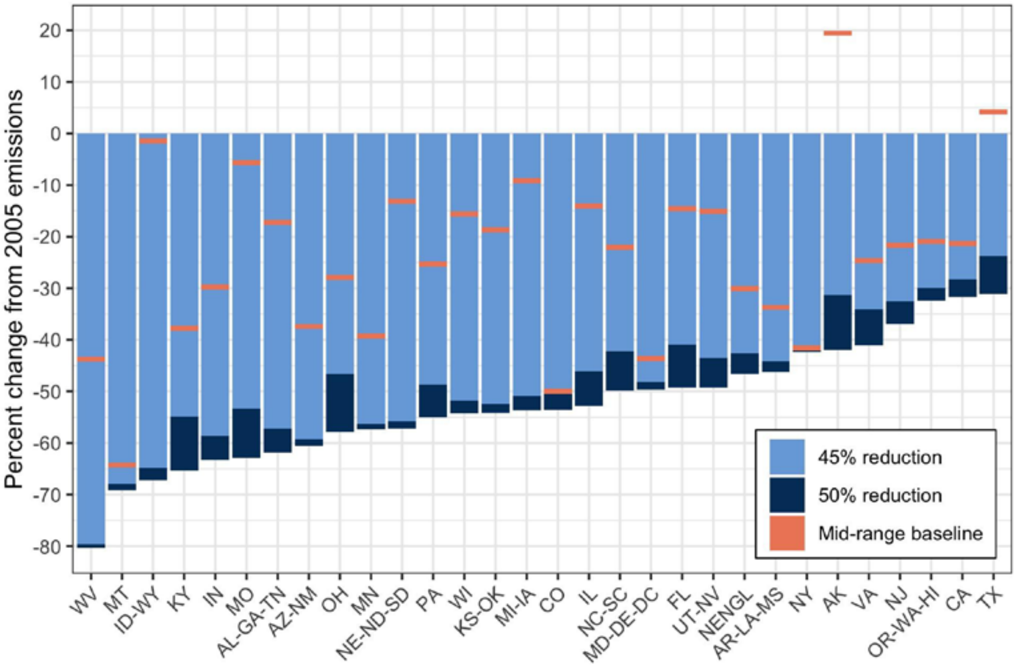

Figure 3. Percent Reduction in 2030 from 2005 Emissions, by State and Region.

Percent reduction in CO$_2$ emissions from a 2005 base year (EMC allocation). Pink crossbars show emissions reductions in the Mid Range Baseline.

vary widely among states, with West Virginia (WV} showing the greatest reduction (80%) and Texas (TX) the least (24%). Projected 2030 emissions of the states and regions are indicated by pink crossbars in the figure, and almost all are well below their 2005 levels. Exceptions are Alaska (AK) and Texas (TX) where projected 2030 emissions are above 2005 levels, and Idaho-Wyoming (ID-WY) where 2030 emissions are about the same as the 2005 level.

The actual response to the carbon price (the amount of light blue bar below the pink line) is generally more similar across states, with some exceptions. States with significant state level policy such as Colorado (CO) and New York (NY) are already at or near the federal target. Also, the detailed results for Montana (MT) shows that its abundant wind resources are economically competitive and lead to the state nearly achieving its federal requirement in the baseline, requiring little more effort.

The further effort required to meet the 50% target (dark blue bars) varies considerably among states. The national level carbon price yields the greatest reductions in states where there are low cost abatement options, such as, for example, shifting away from coal power generation to gas or renewables. WV and MT exhaust most of their low-cost abatement options in the 45% case, and so abate very little additionally in the 50% scenario. Other states such as Kentucky (KY) Ohio (OH) Missouri (MO), and Alaska (AK) pick up more abatement in the 50% scenario, reflecting the location of the next set of least cost options.

Figure 4 shows the same information as Figure 3 but plots the reductions from the Mid Range Baseline projection for 2030 rather than from the 2005 base year emissions. Shown are both tons (bars) and percentage (red dots) for the 45% reduction scenario (top panel) and the 50% reduction scenario (lower panel). The EMC allocation is used as an example; state emissions across the three allocation approaches are nearly identical, with only small differences due to income effects of variation in allowance revenue among states.

In addition, Figure 4 shows abatement in each state coming from the power, transportation, industry, commercial, and residential sectors. Consistent with earlier analysis of potential U.S. carbon prices (Barron *et al.* 2018), the electricity sector is the source of the largest share (~77–81%) of the cost-effective emissions reductions in 2030 in nearly all states.[10] States with significant energy-intensive and fossil energy production such as TX, AK, and Arkansas-Louisiana-Mississippi (AR-LA-MS)

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[10] We note that reductions outside of the electricity sector will become increasingly important after 2030. This analysis may also under-estimate the availability of low-cost reductions in non-electricity sectors due to calibration to historical relationships instead of directly representing emerging low carbon technologies for those sectors.

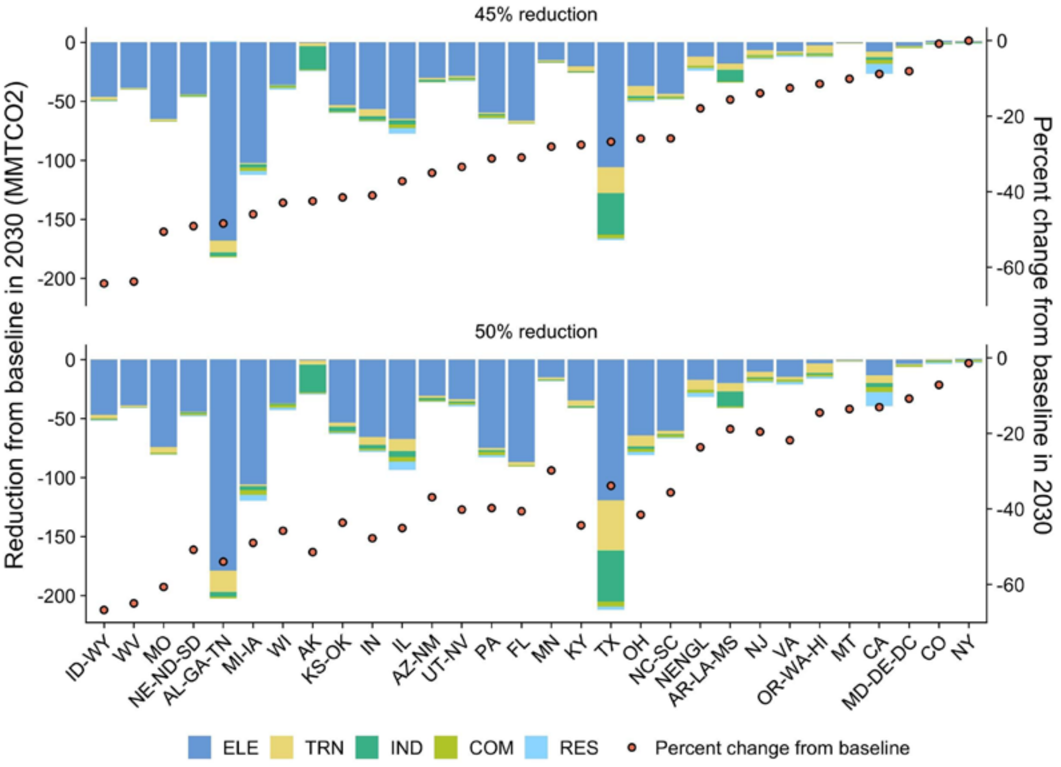

Figure 4. Reduction in 2030 from Baseline Emissions, by State/Region and Sector.

Reductions by sector in 2030 relative to the Mid Range Baseline across states under the EMC allocation. Right-hand axis shows percentage reduction relative to the baseline.

show the greatest reduction in emissions from industry, in part because fossil fuel industries (such as refineries) shrink, lowering emissions from them. AK and MT have very little or no reduction from the power sector relative to the baseline. In AK, the power sector accounts for less than 10% of emissions, so even with a substantial reduction the power sector does not contribute much to the state's overall reduction. As noted earlier, MT has shifted largely to wind power in the baseline, so there are no additional power sector reductions available. Similar to MT, in CA and the RGGI member states—New England (NENGL) and New Jersey (NJ)—the electric sector achieves a large share of reductions in the baseline, leading non-electric sectors to play a bigger role in the overall reduction.

4.2 Regional Economic Impacts

4.2.1 Welfare

The overall social costs and benefits are best captured by a welfare metric. The USREP model provides a measure of welfare at the state level, which is computed as state consumption, taking account of changes in leisure and reflecting both compliance costs and revenue from allowance sales. It endogenously calculates direct welfare effects of mitigation policies, discussed in this section. However, these endogenous estimates do not include welfare improvements from improved air quality or reduced climate impacts. (In Section 4.2.2 we report a net benefit calculation that includes a separate estimate of the health benefits of avoided particulate matter air pollution and of avoided climate damages.)

At the national level, the impacts of the policy on welfare are best described as modest, even before accounting for air quality or climate benefits. Economic welfare continues to grow at almost the baseline rate in all scenarios (**Figure 5**). Achieving a 45% reduction in CO_2 delays the economy reaching its January 1, 2030 level of welfare by only 1.6 months, to mid-February. Meeting a 50% target means that welfare reaches the same level by mid-March (a 2.5 month delay).

The welfare effects differ among the states, and this effect also differs depending on the choice of allocation method (**Figure 6**). States with high emissions in 2005 relative to population such as WV are favored under the ECB. The greatest reduction in welfare growth occurs in the state most heavily dependent on energy production, Alaska (AK). West Virginia (WV) has a noticeable gain in welfare under the ECB allocation due to the significant number of allowances it would receive.

4.2.2 Net Benefits

Table 5 provides national net benefits in 2030 under Section 115 policies relative to the Mid-Range and Low-Cost Baselines. Specifically, they are estimated for 45% and 50% reduction policies under the ECB allocation, as the emissions outcomes vary only a small amount under the different allowance allocation approaches. Net benefits are positive and significant in each scenario, ranging from $72 billion (Low-Cost 45% Reduction; Low Reduced Mortality) to $156 billion (Mid-Range 50% Reduction; High Reduced Mortality). For the same scenarios, reduced mortality ranges from 3,544 to 14,356 in 2030. Health and climate benefits are greater in the 50% Reduction than in the 45% Reduction scenarios, and also are greater under the Mid-Range assumptions than under the Low-Cost Baseline, because the Low-Cost Baseline has lower pollution emissions than the Mid-Range Baseline. Health benefits exceed climate benefits with the High estimate but are less than climate benefits with the Low estimates, and health benefits alone offset negative welfare impacts except under the Mid-Range assumptions with the lower Reduced Mortality benefit estimate.

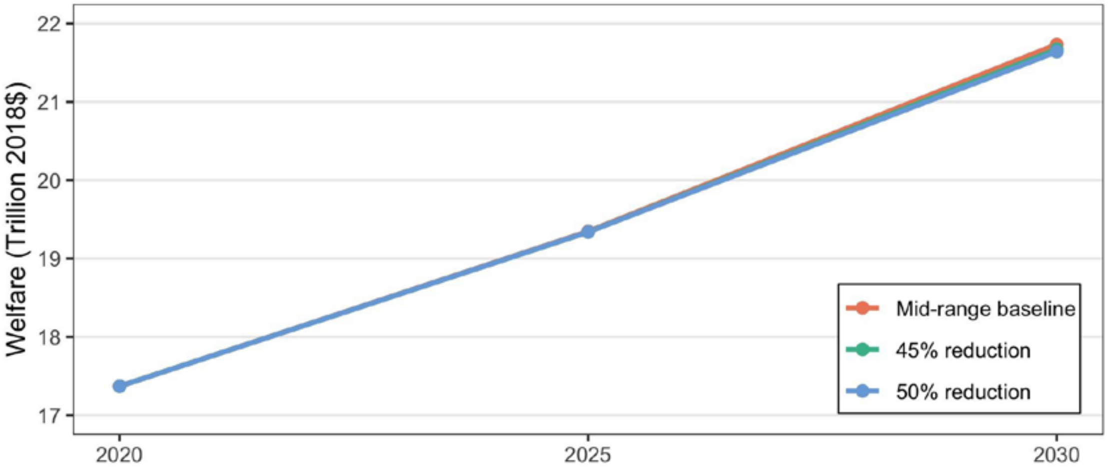

Figure 5. Welfare Growth Over Time.

Projections of baseline growth in economic welfare compared to welfare growth under the 45% and 50% reduction cases (EMC allocation). Welfare estimate does not include health or climate benefits in the policy cases.

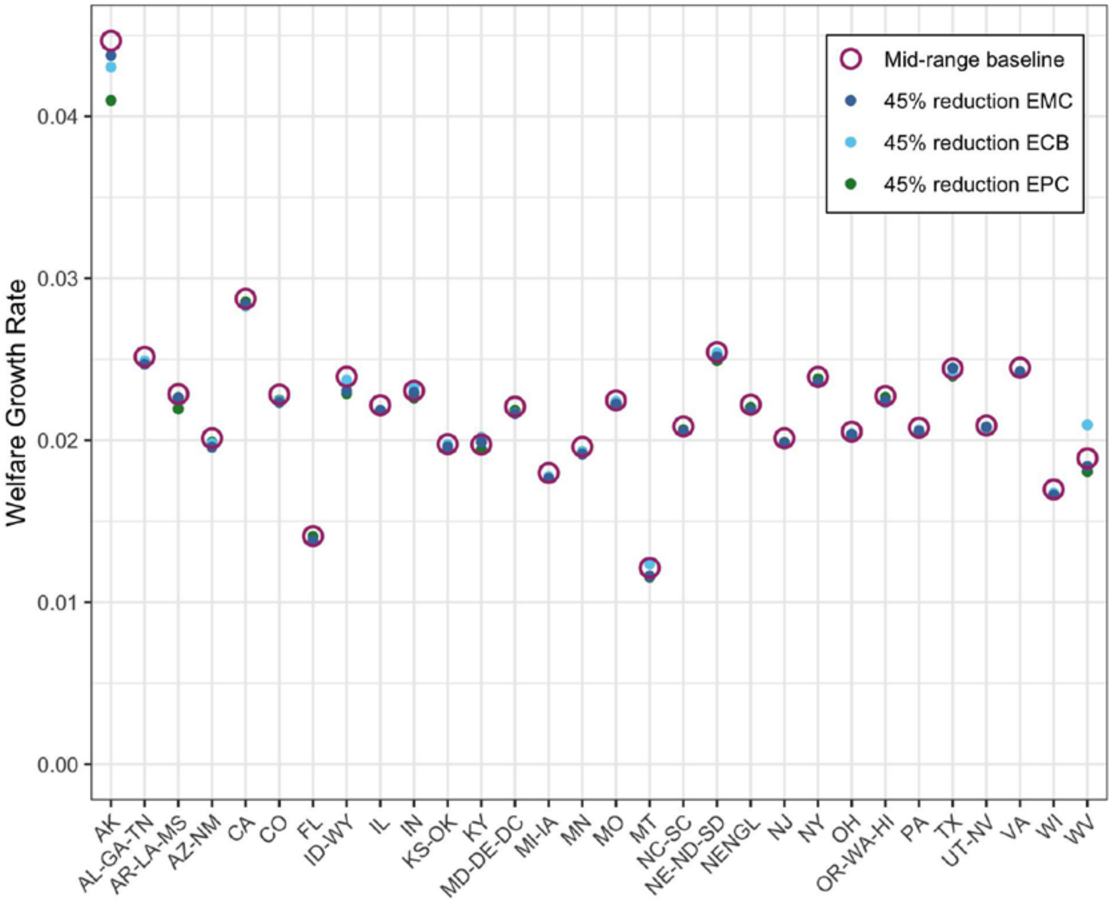

Figure 6. Percent Change in Welfare Growth Rate under EPC, EMC and ECB Allocations.

Compound annual growth rate in welfare 2020-2030 in the Mid Range Baseline (red circles) compared to growth rate in the 45% reduction case under the three allocation methods. Welfare growth does not include health or climate benefits in the policy cases.

Table 5. Net Benefits under Section 115 Policies Relative to Baselines in 2030 (2018$ billion). Note: Air pollution health benefits are only estimated for the continental U.S.

	Mid Range		Low Cost	
US Net Benefits in 2030 (High)	**45% (ECB)**	**50% (ECB)**	**45% (ECB)**	**50% (ECB)**
Reduced Adult Mortality from $PM_{2.5}$ [High]	**11,852**	**14,356**	**8,027**	**10,834**
Climate and Health Benefits [2018$ Bil]	**205**	**248**	**133**	**179**
Health Benefits	123	149	83	112
Climate Benefits	82	100	50	67
Ratio of Health: Climate Benefits	1.49	1.49	1.68	1.68
Change in Welfare [2018$ Bil]	**-60**	**-92**	**-15**	**-29**
Total Net Benefits [2018$ Bil]	**145**	**156**	**118**	**150**
US Net Benefits in 2030 (Low)				
Reduced Adult Mortality from $PM_{2.5}$ [Low]	**5,230**	**6,334**	**3,544**	**4,782**
Climate and Health Benefits [2018$ Bil]	**137**	**165**	**86**	**116**
Health Benefits	54	66	37	50
Climate Benefits	82	100	50	67
Ratio of Health: Climate Benefits	0.66	0.66	0.74	0.74
Change in Welfare [2018$ Bil]	**-60**	**-92**	**-15**	**-29**
Total Net Benefits [2018$ Bil]	**76**	**73**	**72**	**88**

We compare air pollution and climate benefits under the ECB allocation (benefits are nearly identical for all allocations) to the EMC welfare effects for states (**Figure 7**). Welfare effects at the national level are nearly identical for all allocations but vary by state because of varying allowance revenue. Climate benefits are allocated on an equal per capita basis across states.[11] We focus on the EMC allocation for welfare effects because it was the approach taken by the EPA in the Clean Power Plan proposed under the Obama Administration. All states show net benefits for the 45% reduction except Idaho-Wyoming (ID-WY) where benefits just offset welfare costs. Many states show net benefits just considering the value of avoided mortality from particulate matter. As seen earlier, much of the carbon emissions reduction comes from eliminating coal power generation, and so larger air pollution benefits accrue to states that rely on or are near states with coal power plants in the Baseline. These are states in the middle of the U.S. that have higher pollution levels in the Baseline because of reliance on coal power generation, achieving annual net benefits in the range of $400 to $800 per capita. Western, Mountain, and Northeastern states have lower pollution levels in the Baseline or more emissions outside the power sector and see lower air pollution benefits, with net benefits of $0 to $200 per capita.

4.2.3 State/Regional Revenue

The sale of allowances to emitting entities who need them could be conducted by the states themselves, which would then directly receive the revenue. With a uniform national allowance price, the allocation method determines the distribution of funds among the states within the simulated results (Figure B1).[12] The allowance value per capita--the amount states would distribute to each resident if they chose a simple lump sum allocation of revenue--is shown in **Figure 8**. The EPC allocation results in identical per capita allowance revenue in all states—an estimated $669 for the 45% reduction. In the ECB the range is from $356 to $2,403, with California (CA) the lowest and Alaska (AK) the highest. Under the EMC allocation, the range is $424 to $3,046 with New York (NY) the lowest and AK the highest. AK has by far the highest emissions per capita, and so both the ECB and EMC allocation methods are favored over equal per capita allocation. In general, emissions intensive states are favored by the ECB and EMC allocations. West Virginia (WV) and Montana (MT) are especially favored under the ECB allocation because by 2030 their emissions in the baseline have already fallen substantially (and they were emissions intensive in 2005). The total allowance value (i.e., state revenues) accruing to each state is reported in Appendix C.

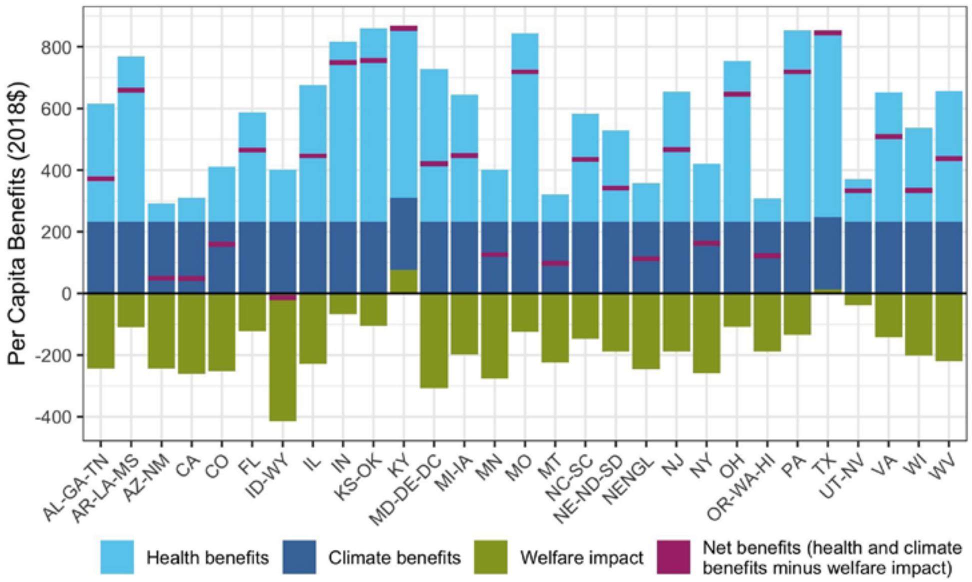

Figure 7. Per capita net benefits by state in 2030 for the 45% reduction, EMC allocation, relative to the Mid Range Baseline.

Air pollution benefits and welfare impacts are those estimated to accrue in the state. Climate benefits are assigned on an equal per capita basis across states.

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[11] Climate benefits will be unrelated to CO_2 emissions reductions in the state because emissions anywhere affect the global climate. Using the social cost of carbon to value climate benefits does not currently provide a basis to differentially allocate benefits to states, although climate benefits will vary geographically within the U.S. The Social Cost of Carbon also includes benefits accruing outside the U.S.; the nuances of how to consider these benefits and associated issues of reciprocity are beyond the scope of this analysis. The interagency working group that developed the U.S. estimate of the social cost of carbon used here also emphasizes the importance of using a range of values when considering the social cost of greenhouse gases - only one value is presented here due to graphical constraints.

[12] Prices in actual allowance markets vary over the course of a year. States may auction allowances at different times, leading to differences in the average price at which allowances are auctioned among states.

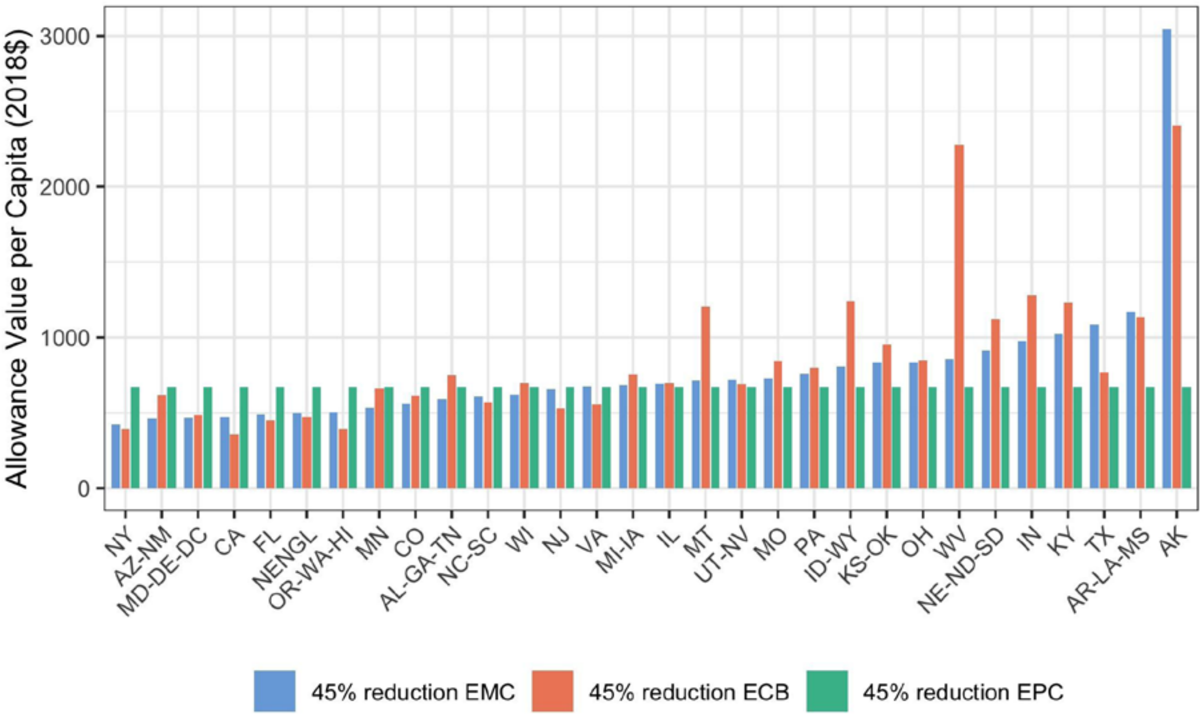

Figure 8. State Revenue Per Capita in 2030 from Allowance Sale, 45% Reduction.

Results are sorted by size of per-capita rebate under equal marginal cost (EMC) allocation.

4.2.4 Distributional Effects

An important concern of policymakers is to avoid regressive policy measures, where costs fall more heavily on lower income households. While the price increases resulting from requiring emitters to hold allowances have the potential to be regressive because low income households spend a larger share of their income on energy, the allowance revenue provides a means to offset these regressive effects.[13] Per capita rebates generally have the effect of making carbon pricing policies progressive, with net *improvements* in welfare to the lowest income households relative to baseline projections (Caron *et al.*, 2018a,b). The welfare effects by income level we report in this section do not include air pollution or climate benefits. Some studies (Hajat *et al.*, 2015) have found health impacts from poor air quality tend to fall on lower-income households in the U.S., which means a Section 115 policy could produce further welfare improvements for those households. This will depend on what sources of pollution are reduced, and further analysis is needed to determine if the abated pollution sources disproportionately contribute to the health problems of lower income households.

In our analysis, shown in **Figure 9**, the per capita rebates lead to modest welfare improvements for the lowest income quintile (relative to the baseline) in all fifty states under a 45% reduction. The second income quintile also sees welfare improvements in regions representing 19–33 states with 36–51% of the U.S. population, depending upon the allocation approach.[14] The largest reductions in welfare growth are generally in the highest income quintile, with the impact still usually less than 1%. At the national level, this translates to a delay of 1.3 to 9.6 months in reaching the baseline welfare level of 2030 for the highest income quintile, depending upon the region and allocation approach. Across states and regions there is, as expected, variability in the patterns of the distributional impacts.

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[13] Equal lump sum distribution of allowance revenue tends to be progressive because even though lower income households spend a larger share of their income on energy, their absolute level of expenditure is much less than wealthier households. In addition, our background assumption of holding total tax revenue unchanged (in real terms) maintains federal expenditures, including transfer payments, constant, essentially indexing transfer payments for any price changes. Such indexing of transfer payments also contributes to policy progressivity (Cronin *et al.*, 2017; Goulder *et al.*, 2018), although only for those who receive significant transfer payments (i.e., not necessarily the working poor).

[14] Under the 50% reduction, depending on the allocation method the lowest income quintile sees welfare improvements in 49 to 50 states containing 94 to 100% of the US population. Welfare in the second income quintile improves in 19 to 27 states with 31 to 46% of the U.S. population.

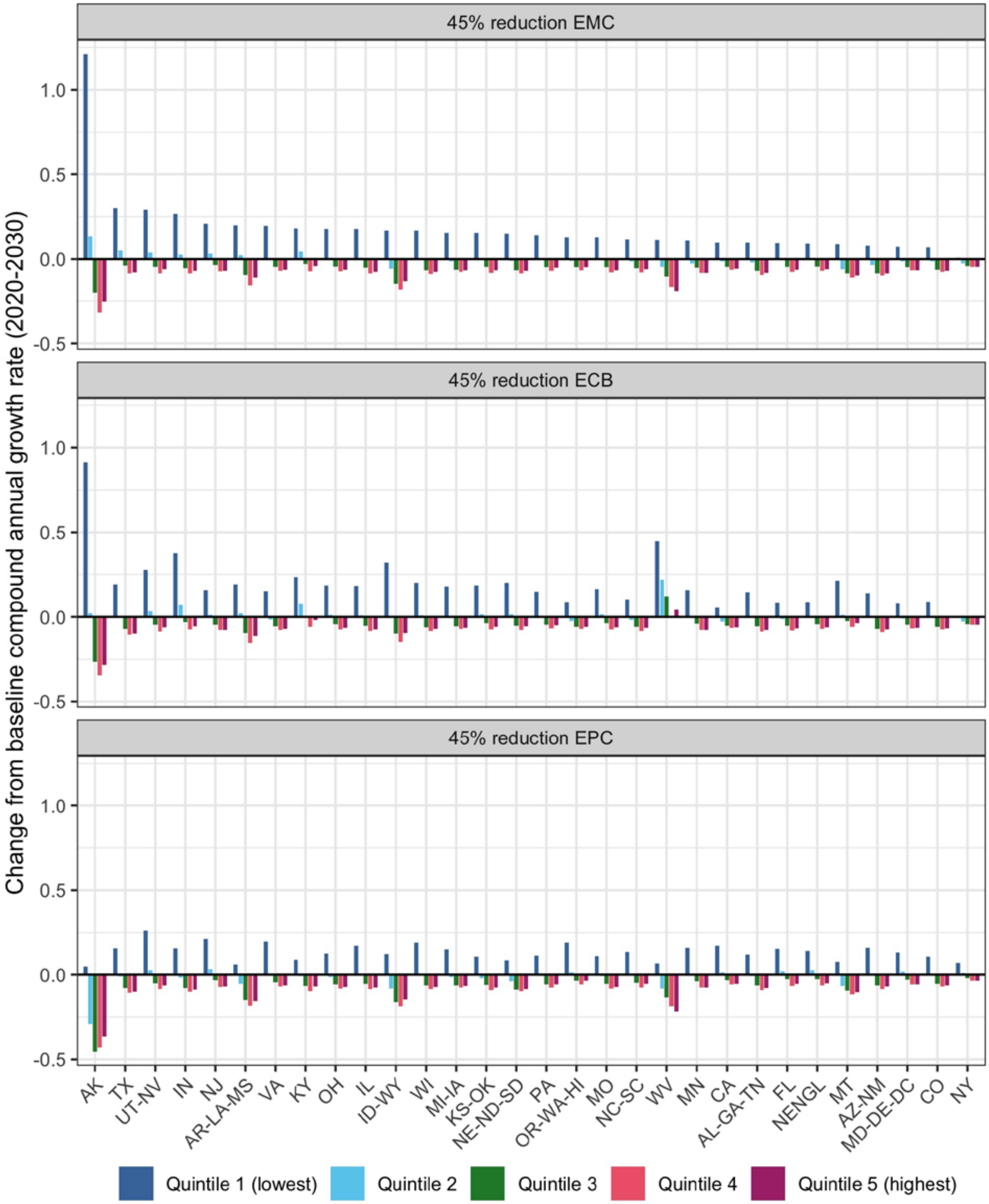

Figure 9. Distributional Impact by Income Quintile, 45% Reduction by EMC, ECB, EPC Allocations.

State welfare impacts, stated as a change in compound annual growth, by national income quintile under each allocation method. Does not include air pollution or climate benefits.

5. Discussion

This analysis explores the effects of a carbon allowance program in the U.S. as it might be implemented under Section 115 of the Clean Air Act. As with similar other CAA programs, EPA would lay out goals and guidelines, but would leave the implementation details to be decided by the states. Economic efficiency would be best achieved through a trading program with broad scope, but a state could choose other policies, such as command and control measures, to meet its target if they better met individual circumstances and policy goals.[15] Section 115 is well-suited to establishing a trading program with broad scope, but the analysis presented here could be generally applicable to the establishment of a trading program under other authorities. Details of implementation, under Section 115 or other authority, could obviously lead to different results and, as illustrated by the Low-Cost Baseline, future technology costs and energy efficiency gains could significantly affect results. Varying the national targets, the allocation of emission reduction responsibilities among states, or what states do with the allowance revenue would affect costs and relative impacts among states and the distributional consequences within states. For example, the assumption applied here, equal per capita lump sum distribution of allowance revenue, is progressive. In contrast, free distribution of allowances to polluters tends to be regressive because the allowances go largely to corporations, leading to windfall profits that ultimately are distributed to shareholders, who are mostly upper income households.

Because Section 115 would be implemented through a SIP process, the costs, benefits and impacts attributable to the program would also depend on the emissions policies already in place in a state when the program goes into effect. For example, our analysis shows that states such as Colorado, New York and California, which already have ambitious economy-wide programs, would need to achieve few, if any, additional reductions to comply with the program (Figure 3). Technology advances, such as falling solar cost, as assumed in the Low-Cost Baseline, might enable other states such as Arizona and New Mexico to meet their goals with little additional effort as well, as shown in Appendix B. Broad federal measures such as efficiency standards, more ambitious vehicle emissions standards, public health regulations, tax incentives, and direct federal investment (including post-COVID stimulus) will also further reduce baseline emissions and the need for states to adopt additional measures. Such additional federal measures would lower costs of the Section 115 program, and perhaps bring results closer to those in the Low-Cost Baseline.

Though the bulk of the reductions (77% to 81%) are found to come from the electricity sector, the mix of reductions highlights advantages of this economy-wide approach. First, the substantial fraction of reductions that come from outside the electricity sector suggests that there are cost-effective reductions that can be achieved there, which may be more difficult to achieve through sector-specific policies. We also note that, while our coupled model represents the electricity sector in great detail, there is much less detail for the other sectors. It is possible that a more complete representation of existing and emerging technologies in non-electric sectors could reveal additional cost-effective reductions. Second, a consistent price signal across the overall economy can help avoid leakage across sectors that might slow decarbonization (e.g., higher electricity prices with no pressure on natural gas use outside the electric sector would discourage electrification). Finally, establishing a program with broad scope now will spur continued emissions reductions after the electricity sector has largely been decarbonized, which will be essential to further reductions post-2030.

Our results suggest that, using Section 115, the cost of cutting GHG emissions to 45% to 50% below 2005 levels by 2030 is very modest. This result is due in part to ambitious existing state policies, falling renewable energy costs, and low natural gas prices. Considering health benefits using estimates of particulate matter air pollution health benefits and climate benefits using the social costs of carbon, less the mitigation costs, we find net benefits to the US in all cases, with slightly larger net benefits with the 50% reduction.

The EPA's Science Advisory Board has recommended that economy-wide models should work to incorporate the economy-wide ripple effects of health benefits in analysis of air and climate policies (SAB, 2017). Our calculation of air pollution and climate benefits are exogenous calculations using a more conventional approach valuing mortality at the value of a statistical life and climate benefits using the social cost of carbon. Bringing at least some of the health benefits inside the CGE framework remains an important area for future analysts.

The analysis also shows how regional disparities in the welfare cost can be moderated somewhat by the allocation of allowances among states. There is a strong correlation in emissions, costs of reduction, and population among states, so the differences resulting from different allocation procedures are relatively small for most states. Still, allocation by marginal cost (EMC) or reduction from base year (ECB) appear better than per-capita (EPC) at reducing the negative outliers in state cost impacts. While we focused on three basic approaches for illustrative purposes, EPA could formulate other approaches, including combinations of these three, to further reduce disparities across states and regions.

Consistent with earlier studies on carbon pricing policies (Caron, 2018b; Rosenberg *et al.*, 2018; Metcalf, 2019), our

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[15] For example, some states such as California and New York have increasingly focused on ways to combine market measures with tools to address environmental injustice.

results show that equal lump sum payments to state residents generally lead to net benefits to lower income households across the majority of the population. While states may choose other policy approaches or other uses of the revenue from allowance sales, maintaining a significant per capita or targeted low-income rebate will keep the policy progressive with respect to income.

While we have focused on the balancing of emissions reductions and costs across states, it is important to recognize that EPA and the states face other design considerations not discussed here. For example, States may wish to modify allowance allocation or other aspects of their SIPs to protect energy intensive industry from international trade exposure (Dotson, 2020). Similarly, while a trading system can help ensure economically efficient outcomes, and per-capita rebates *improve* welfare for lower income households, states and EPA may want to do even more to address existing disparities in exposure to air pollution. For example, EPA may wish to require states to take steps to ensure that their SIP processes engage environmental justice communities in a meaningful way and that the states consider policies to ensure that trading mechanisms do not exacerbate (and ideally reduce) existing disparities.

Section 115 clearly offers significant potential to achieve GHG reductions. Unfortunately, the lack of case law, or consideration of this application by the federal courts, suggest there is also legal risk. The legislative history of the Act indicates that climate concerns were on policymakers' radar when the provision was enacted (Barnett, 2020), but others suggest that courts may be skeptical of drawing such expansive authority from a brief and heretofore rarely used part of the Act (Richardson, 2017). Ultimately, any legal risk must be weighed against the environmental benefits and other policy advantages, which can be more fully assessed with further analyses like the one we present here.

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Appendix A: Emissions Control Measures in the AEO Reference and Baseline

Measures to Promote Low-Carbon Electricity Generation

Figure A1 shows the Renewable Portfolio Standard (RPS) imposed by states in ReEDS. The policy stringency in the AEO Reference and Mid Range Baseline is represented by a solid bar and a shaded bar, respectively. A red shade represents a less stringent policy measure in the Baseline relative to the AEO Reference, whereas a blue shade represents a Baseline policy stringency no less than that in the AEO Reference. A green shade marks the policy stringency in a state where no policy exists in the AEO Reference. A significant number of these adjustments are to reflect the fact that state RPS policies often only cover investor-owned utilities, exempting rural electric cooperatives and municipal utilities and effectively reducing the stringency of the program.

Similar to RPS, the policy stringency of Clean Energy Standards (CES), and wind and solar carveouts differ in some states (**Figure A2**). The comparison is drawn with the same color and pattern convention as in Figure A1.

Other State Emissions Abatement Policies

In three states emissions control measures are considered that extend beyond the electric sector.

Table A1. Economy-Wide State Control Measures

State	Coverage	Unit	2020	2025	2030
NY	Economy-Wide Cap	MMTCO$_2$e	156	140	122
CO	Economy-Wide Cap	Percent below 2005		26%	50%
CA	Economy-Wide Cap*	2018$/tCO$_2$		$65	$83

* The Agriculture and Other sectors are exempted from AB32 cap. For technical reasons the emissions cap is achieved in the model using a tax instrument.

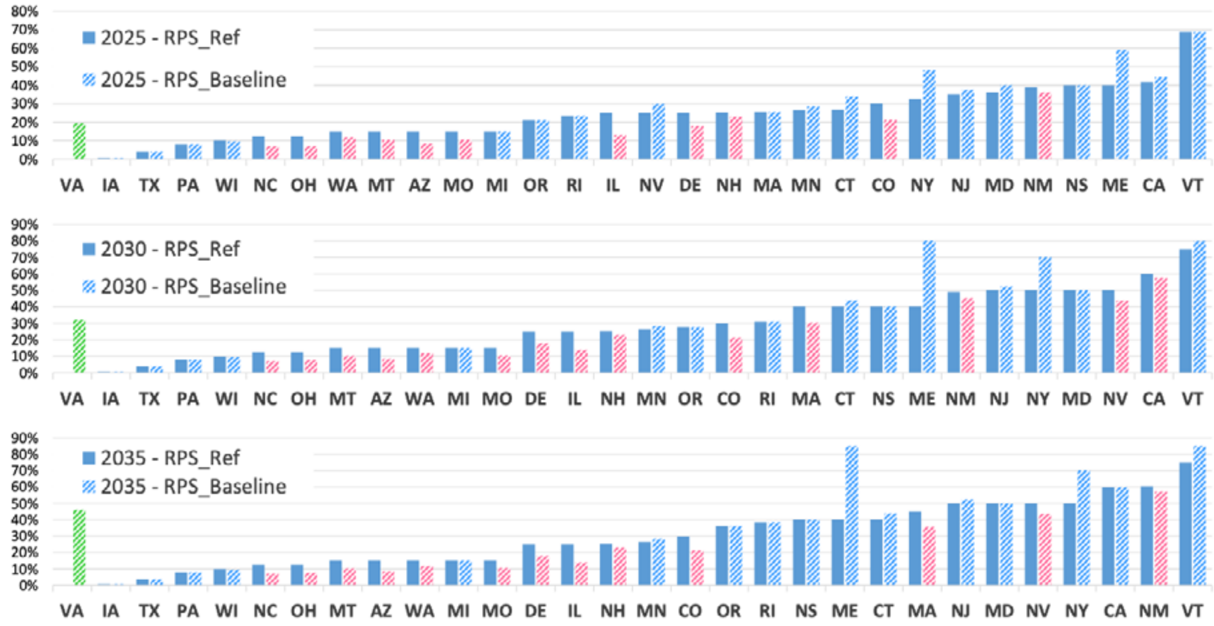

Figure A1. Renewable Portfolio Standards by state

The AEO reference is compared with the Mid Range Baseline

Figure A2. Clean Energy Standards and wind and solar carveouts by state

The AEO reference is compared with the Mid Range Baseline.

Appendix B: Low-Cost Baseline Results

Projections of future costs of policies are uncertain, with baseline projections of key technologies like wind and solar often failing to keep pace with falling prices. While a full sensitivity analysis is beyond the scope of this study, we explore how the impacts of a program under Section 115 would change if technology costs were lower than projected and states (perhaps with Federal support) invested more in energy efficiency.

To account for the possibility of more rapid declines in renewable energy costs, parts of the analysis were repeated with NREL's "Low" rather than mid-cost assumptions (NREL, 2019). See **Figures B1, B2, B3 and B4**.

To account for the possible breakthrough in the battery technology in electric vehicles, we ran the model with electric vehicles achieving cost parity with conventional internal combustion engine vehicles by 2030.[16] Noting that energy efficiency has been a key component of the strategies of many leading states, this scenario also includes the assumption of significant additional investment in energy efficiency. To approximate this effect, we assume that each state accomplishes a rate of endogenous energy efficiency improvement that matches the historical rate in California over the period 1999-2008. This rate could be achieved through a combination of tightened federal efficiency standards, federal investment (perhaps as part of a COVID-19 recovery package), and state level actions (either with allowance revenue or revenue from other funding sources).

In general, the Low-Cost Baseline results in a similar pattern of emissions reductions, with roughly 78% of reductions in 2030 coming from the electricity sector, and similar patterns regarding where costs occur across regions. As expected, overall and regional welfare costs are even smaller under this scenario.

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[16] This assumption is not particularly aggressive; both the International Council on Clean Transportation and Bloomberg New Energy Finance project cost parity well before this point.

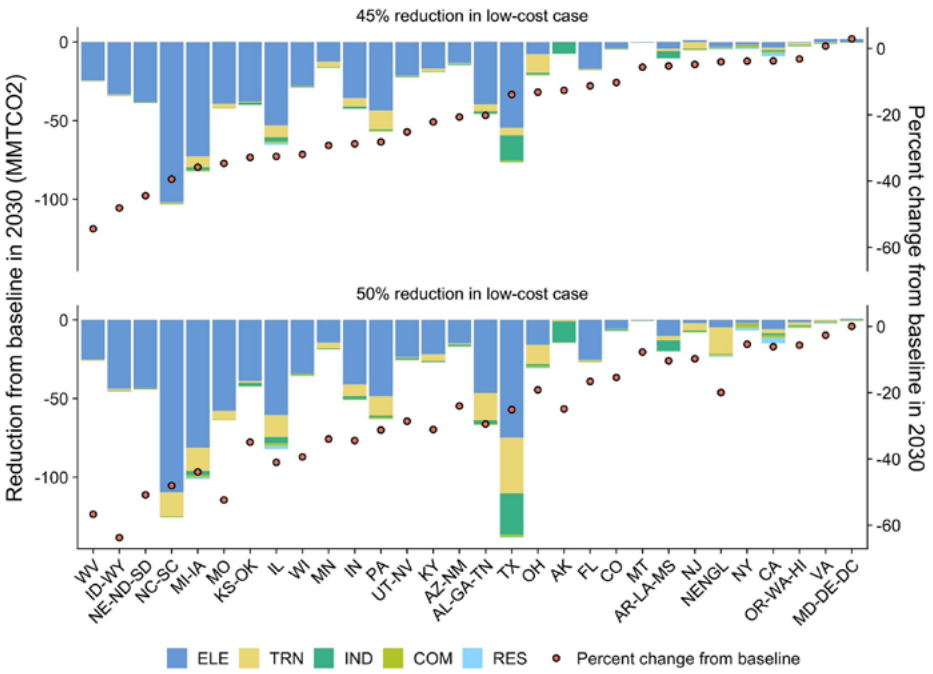

Figure B1. Reduction in 2030 from Low-cost Baseline Emissions, by State and Region, Low Cost Baseline.

Reductions by sector in 2030 relative to the Low-Cost Baseline across states under EMC allocation. Second axis shows percentage reduction.

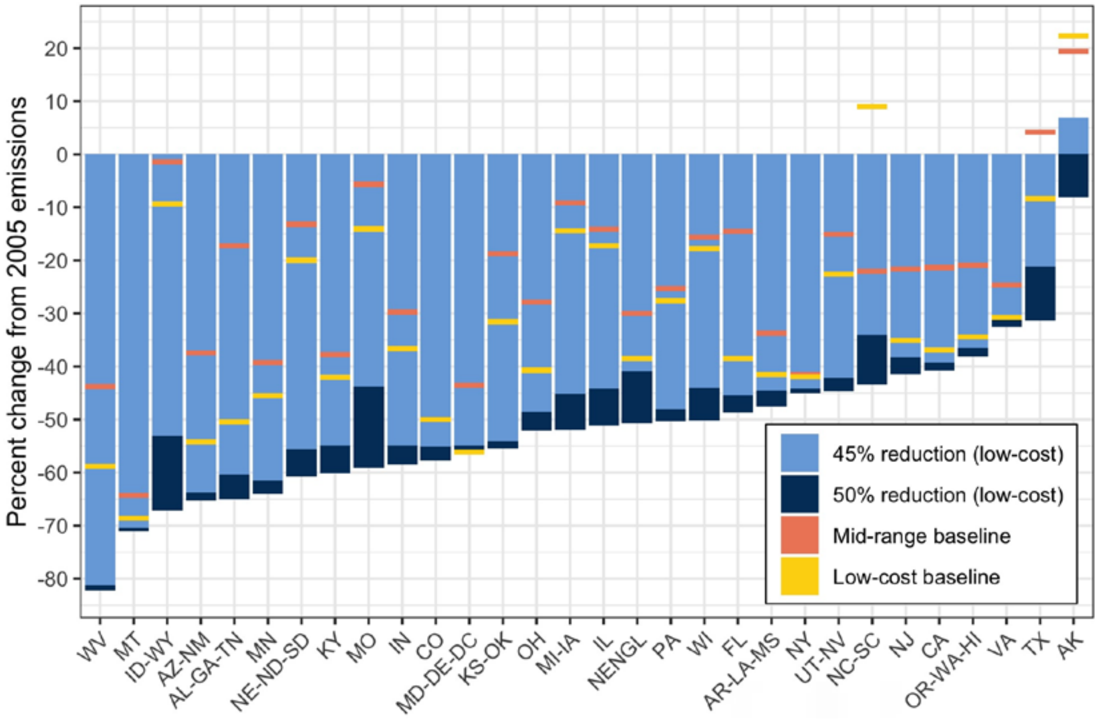

Figure B2. Percent Reduction in 2030 from 2005 Emissions, by State and Region, Low Cost Baseline.

Percent reduction in CO_2 emissions from a 2005 base year (EMC allocation) under the Low-Cost Baseline. Orange crossbars show projections of the reduction in emissions in the Mid-Range Baseline. Yellow bars show projections of emissions under the Low-Cost Baseline. Results are similar to the Mid Range Baseline with some exceptions. For example, the need to reduce less nationwide because emissions in the Low-Cost Baseline are lower, creates room for Alaska emissions to be higher than their 2005 level (but still reduced from the 2030 Baseline). Also, NC-SC emissions are higher in 2030 in the Low-Cost Baseline than in the Mid Range Baseline. Higher emissions result because some coal power plants remain to balance greater penetration of intermittent renewables.

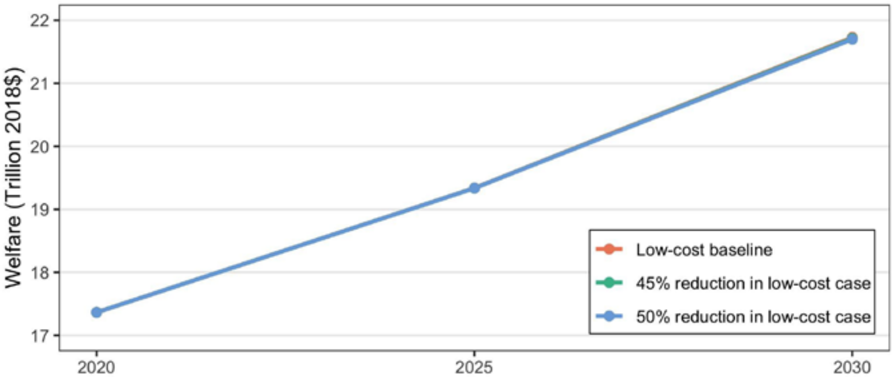

Figure B3. Welfare Growth Over Time, Low Cost Baseline.

Low Cost Baseline projections of growth in economic welfare compared to welfare growth under the 45% and 50% reduction cases (EMC allocation). Welfare estimate does not include health or climate benefits.

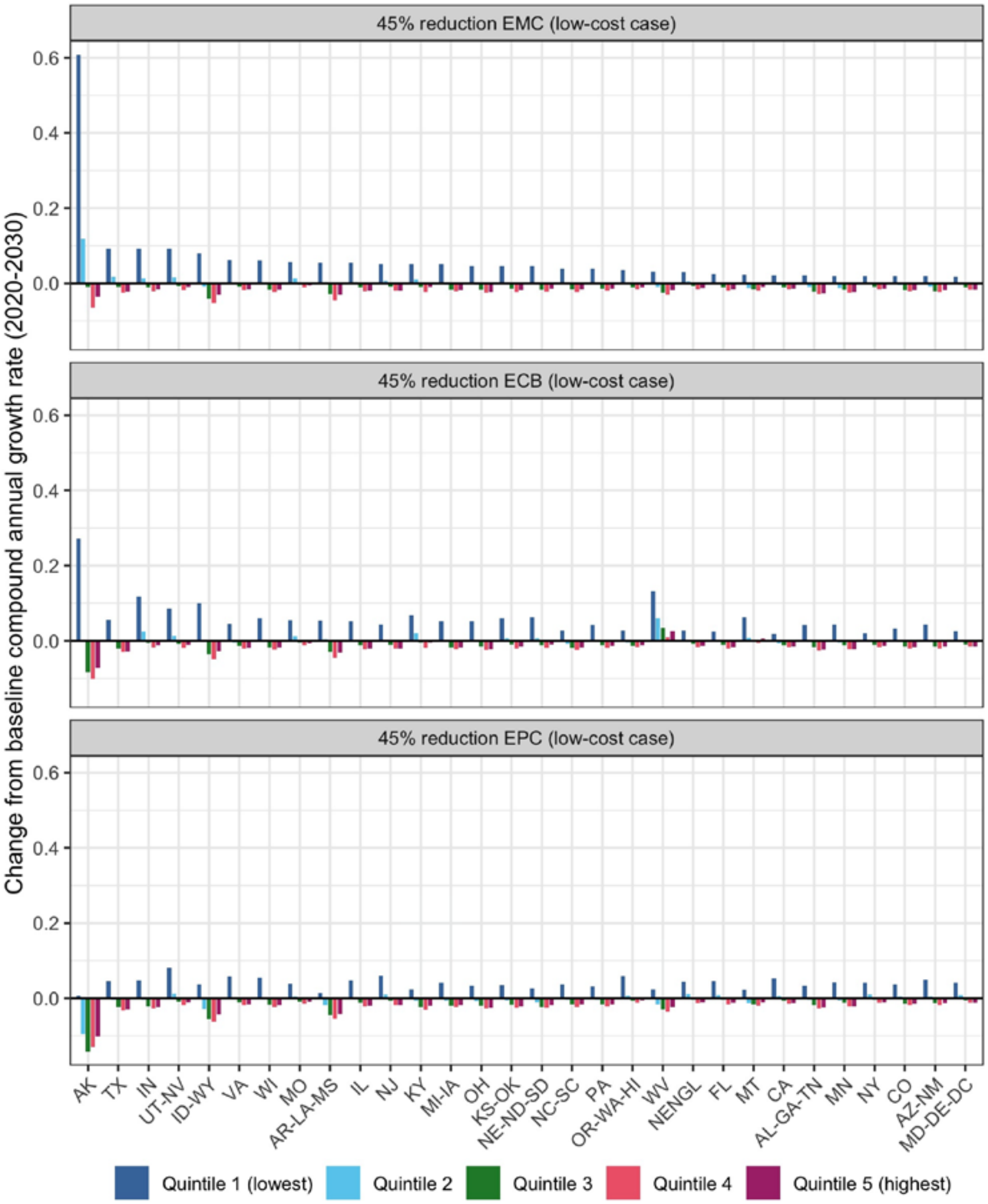

Figure B4. Distributional Impact by Income Quintile, 45% Reduction by EMC, ECB, EPC, Low Cost Baseline.

State welfare impacts, stated as a percentage change, by national income quintile under each allocation method.

Appendix C: Revenue from Allowance Sale by Allocation

Figures C1 and C2 show state revenues under Mid Cost and Low Cost Baselines. Since population, energy use, and emissions are highly correlated, large states generate higher allowance revenue in all three of our allocation rules. States with lower emissions per capita generally have greater allowance revenue under the EPC allocation. Note that California (CA) as the most populous states generates the highest allowance revenue under this allocation approach, but falls to 2nd and 3rd under the EMC and ECB approaches because many opportunities to abate emissions have already been exploited under state initiatives, and base year emissions (per capita) were already much lower than, for example, Texas (TX). And, for example, West Virginia (WV) generates much more revenue under the ECB approach because it had relied so heavily on coal power generation but had reduced reliance on coal by 2030 in either Baseline, and could switch further to other power sources at relatively low cost in the policy scenarios. The main difference between the two Baselines is total allowance value is much lower in the Low-Cost Baseline because allowance prices are much lower.

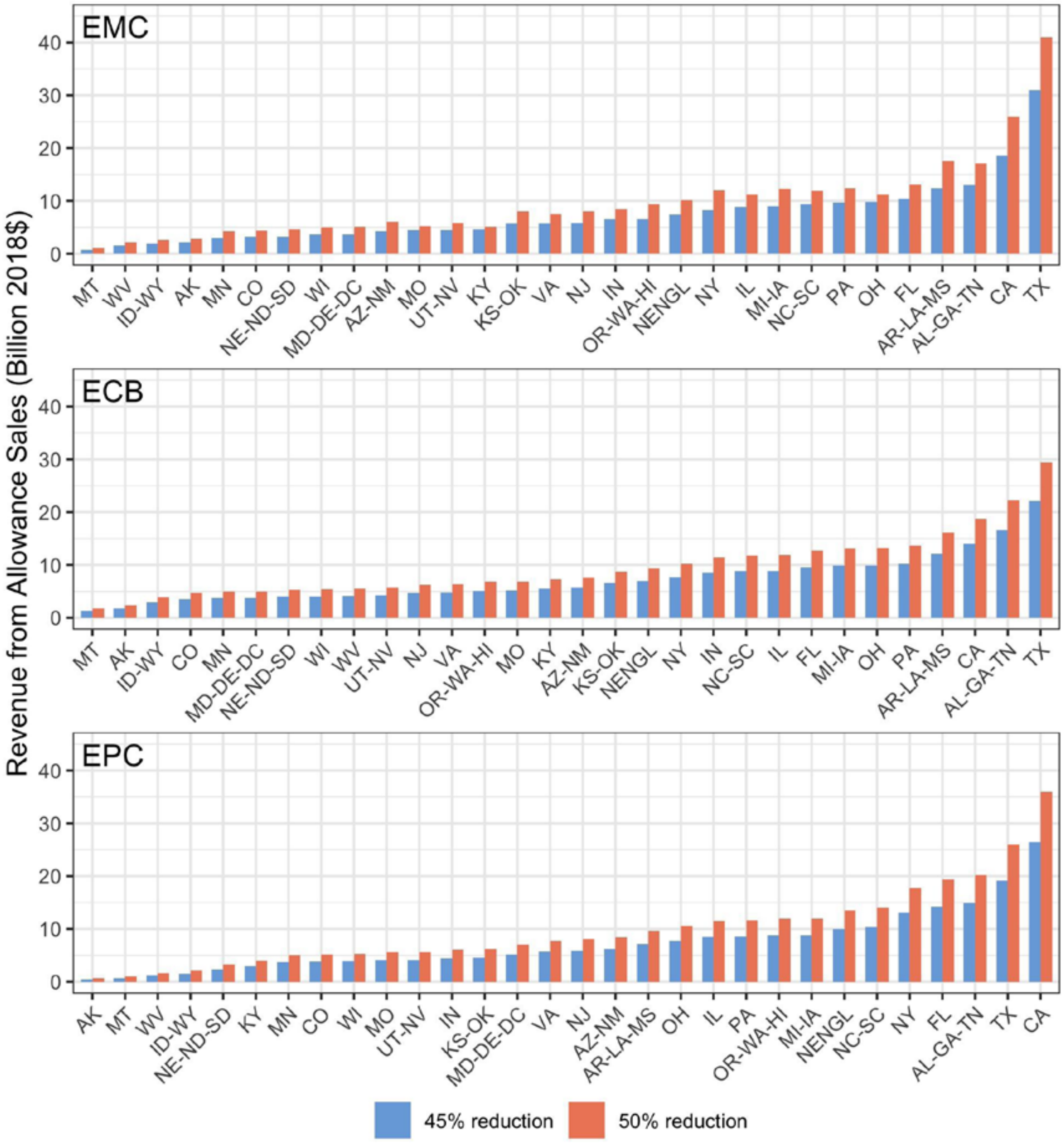

Figure C1. State Revenue in 2030 from Allowance Sale, EPC, EMC and ECB Allocations under Mid-Range Baseline Assumptions.

Differences in revenue among states largely reflect the size of the state in terms of abatement potential, base year emissions or population.

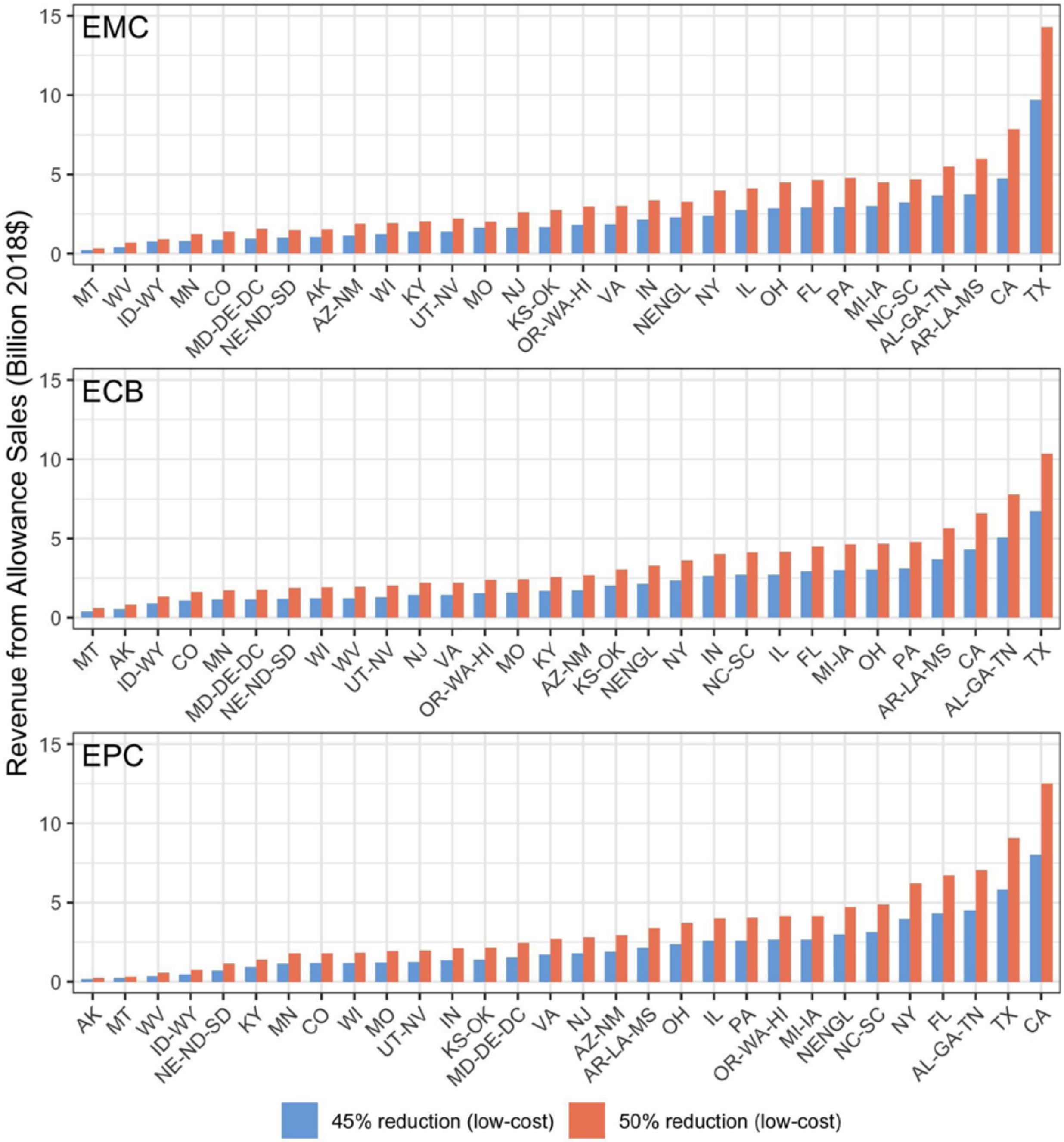

Figure C2. State Revenue in 2030 from Allowance Sale, EPC, EMC and ECB Allocations under Low-Cost Baseline Assumptions.

Revenue to states under the Low-Cost Baseline are about one-third that in the Mid-Range Baseline, reflecting the lower allowance price.

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