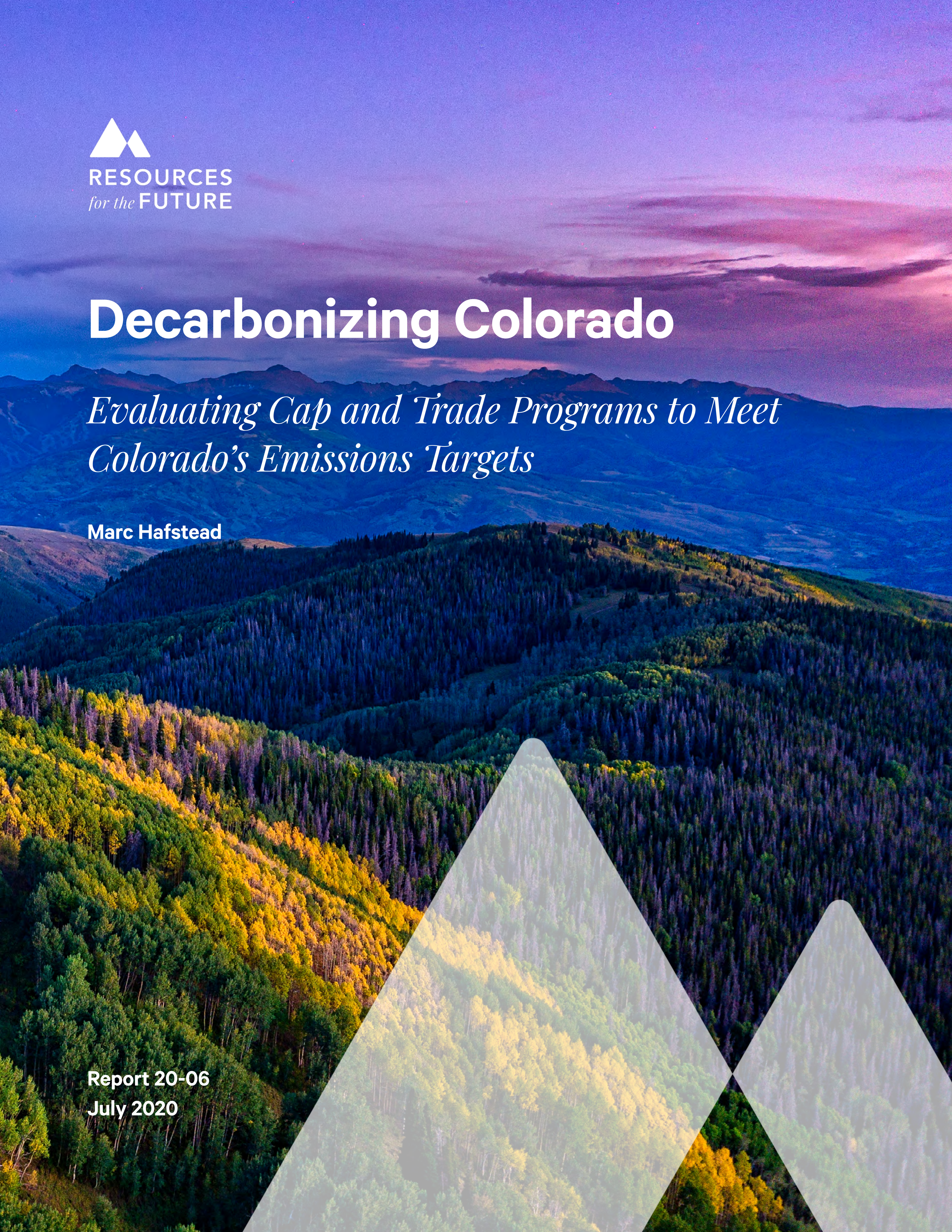

RESOURCES *for the* FUTURE

Decarbonizing Colorado

Evaluating Cap and Trade Programs to Meet Colorado's Emissions Targets

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About the Author

Marc Hafstead is a fellow at Resources for the Future (RFF). He joined RFF in 2013 from Stanford University. His research focuses on the evaluation and design of climate and energy policies. With Stanford Professor and RFF University Fellow Lawrence H. Goulder, he wrote *Confronting the Climate Challenge: US Policy Options* (Columbia University Press) to evaluate the environmental and economic impacts of carbon taxes, cap-and-trade programs, clean energy standards, and gasoline taxes using a sophisticated multi-sector model of the United States. His research also analyzes the distributional and employment impacts of carbon pricing and the design of tax adjustment mechanisms to reduce the emissions uncertainty of carbon tax policies. His work has been featured in the popular press, including the *Wall Street Journal*, the *Washington Post*, Axios, and CNNMoney.

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About RFF

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Executive Summary

Colorado has committed to reduce its net greenhouse gas (GHG) emissions to 26 percent below 2005 levels by 2025, 50 percent below 2005 levels by 2030, and 90 percent below 2005 levels by 2050 through House Bill 19-1261, signed into law by Governor Jared Polis in May 2019.

Despite committing to numerous policies to reduce future GHG emissions, including, but not limited to the adoption of both low- and zero-emission vehicle standards, regulations requiring reductions in emissions from delivered electricity, enhancements to the state's existing regulations on methane emissions from oil and gas operations, and a phase out of the use of certain HFCs, the state's business-as-usual emissions are projected to be well above emissions targets in both 2025 and 2030. Additional policy will be required for the state to meet its goals.

Cap-and-trade programs have been successfully used to cost-effectively reduce emissions around the globe. This report investigates the environmental and economic impacts of two illustrative cap-and-trade programs designed to meet Colorado's midterm emissions targets using the RFF-DR CGE model, a multi-sector and multi-region computable general equilibrium (CGE) model of the United States.

The analysis demonstrates that cap-and-trade programs that provide flexibility in when and where emissions reductions are achieved increase the cost-effectiveness of cap-and-trade programs and deliver climate-related and local health benefits to Colorado that exceed various measures of program cost. Program measures that provide such flexibility across time and space include the use of offsets, linking the program to existing or new multi-state initiatives, and allowing for the use of banking (and/or borrowing) of allowances over time.

The report considers two types of cap-and-trade programs. A Colorado-only program and a WCI-linked program, where Colorado joins California and Quebec in the Western Climate Initiative. The CO-only cap-and-trade program introduces offsets (in a limited amount) and allows for banking of allowances over time to achieve the state's cumulative emissions target between 2021 and 2030. The WCI-linked program provides additional flexibility and is more cost-effective than the CO-only approach, a reflection of the much lower allowance prices in the WRI program relative to the projected allowance prices under the CO-only program and the benefits of providing flexibility to allow for the most cost-effective reductions across participating jurisdictions.

The report also demonstrates that an economy-wide cap-and-trade program, whether for Colorado only or linked to other states, is also likely to be much more cost-effective than sector-specific mitigation strategies. We find significant differences in the abatement costs across sectors which suggests a need for an approach that allows for different levels of emissions reductions by sector.

The ongoing COVID-19 pandemic provides a particularly acute and salient reminder of the uncertainty and inherent difficultly in projecting policy-related environmental and economic impacts over the next decade and beyond. Further analysis is also required to study the effects of the COVID-19 crisis on future energy demand and supply and to consider the impacts of key program design elements such as the coverage of imported electricity and the allocation of allowances that are beyond the scope of this report.

Contents

1. Introduction

Colorado Governor Jared Polis signed the Climate Action Plan, House Bill 19–1261, into law on May 30, 2019.[1] This legislation commits the state of Colorado to reduce its net greenhouse gas (GHG) emissions to 26 percent below 2005 levels by 2025, 50 percent below 2005 levels by 2030, and 90 percent below 2005 levels by 2050.[2] The Act requires the Colorado Air Quality Control Commission (AQCC) to develop regulations consistent with these targets[3] and Senate Bill 19–096 requires the AQCC to "propose rules to implement measures that would cost-effectively allow the state to meet its greenhouse gas emission reduction goals."[4]

This report is designed to assist Colorado policymakers and stakeholders in considering policies to reduce greenhouse gas emissions in an economically and environmentally effective manner. This analysis reviews the state's historical pattern of emissions and existing state actions to cut greenhouse gas emissions. Business-as-usual (BAU) projections predict that additional policies will be necessary to meet both the 2025 and 2030 midterm targets. We investigate the role of a cap-and-trade program on Colorado's energy-related carbon dioxide emissions to meet these targets using an economy-wide and multi-region computable general equilibrium (CGE) model of the United States.

Our findings show that such a cap-and-trade program in Colorado can play an important role in cost-effectively reducing net greenhouse gas emissions when appropriately designed. An appropriately designed cap-and-trade policy will promote cost-effectiveness through measures intended to provide flexibility in achieving reductions across both space and time. These measures include the use of offsets, linking the program to existing or new multi-state initiatives, and allowing for the use of banking (and/or borrowing) of allowances over time.

Emissions pricing through either cap-and-trade programs or a direct tax on emissions is just one of many options for reducing greenhouse gas emissions. Economists point out many advantages of emissions pricing relative to alternative options such as sector-specific mandates and regulations. First, emissions pricing does not require firms to reduce emissions through any particular way; firms are allowed to find the

1 State of Colorado, Seventy-Second General Assembly, **"Concerning the Reduction of Greenhouse Gas Pollution, and in Connection Therewith, Establishing Statewide Greenhouse Gas Pollution Goals and Making an Appropriation."**

2 C.R.S. § 25-7-102(2)(g).

3 C.R.S. § 25-7-105(1)(e)(II).

4 State of Colorado, **"Concerning the Collection of Greenhouse Gas Emissions Data to Facilitate the Implementation of Measures That Would Cost-Effectively Allow the State of Meet Its Greenhouse Gas Emissions Reductions Goals, And, in Connection Therewith, Making an Appropriation."**

lowest-cost way to reduce emissions. Second, broad-based emissions pricing programs equalize the cost of reducing an additional ton of emissions across firms and sectors, which leads to a cost-effective outcome; cost-effective emissions reductions cannot be achieved if a regulator requires excess reductions from a particularly high-cost sector (and consequently doesn't require enough reductions from a low-cost sector). Third, emissions pricing tends to promote more demand-side conservation than sector-specific mandates or regulations. Fourth, emissions pricing provides an economic signal to guide research, innovation and investment. Finally, emissions pricing policies can raise revenues (through auctioning of allowances under a cap-and-trade program, for example) and the use of revenues can promote cost-effectiveness, equity of policy impacts, and/or provide incentives to maintain business activity in the state.

In particular, cap-and-trade programs are emissions pricing systems that are designed to meet emissions targets regardless of changes in the relative costs of various technologies, the turnover rates in vehicles, and other uncertain drivers of emissions and emissions reductions. A cap-and-trade program can also be designed to complement policies that promote and accelerate the energy transformation through changes in infrastructure, directed technical change, and investment throughout the state.

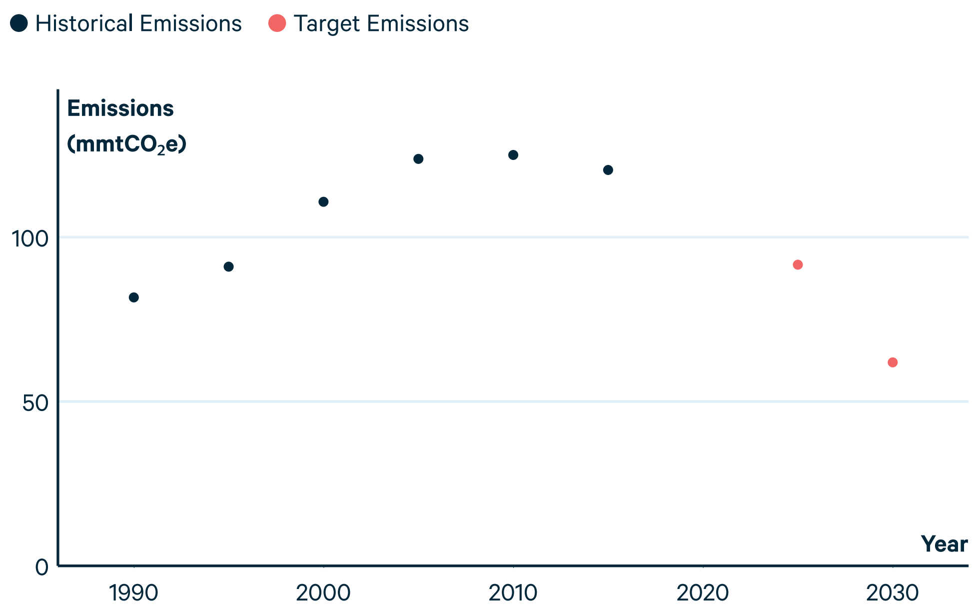
Of course, modeling the environmental and economic impacts of different policies to reduce greenhouse gas emissions over the next decade and beyond is inherently difficult and subject to enormous uncertainty. The ongoing COVID-19 pandemic provides a particularly acute and salient reminder of this uncertainty as we have very little idea how energy demand and supply will change going forward in response to the virus. As with any modeling exercise, the analysis here should be interpreted as a projection of potential outcomes based on multiple layers of assumptions and not a forecast of what will precisely occur if such a policy were to be pursued. With that said, it is hard to envision how Colorado will achieve its deep short- and mid-run emissions reductions targets without policies that promote the flexibility to achieve reductions cost-effectively across sectors, time, and space.

2. Colorado Context

2.1. Colorado Emissions Trends and Targets

Colorado's net GHG emissions grew from 82 million metric tons of carbon dioxide equivalent (mmtCO_2e) in 1990 to 123 mmtCO_2e in 2005.[5] Growth in emissions fell considerably between 2005 and 2010 and emissions actually decreased for the first five-year period on record between 2010 and 2015 to 120 mmtCO_2e.[6]

Figure 1. Colorado GHG Emissions Trendsbank, 1990–2015



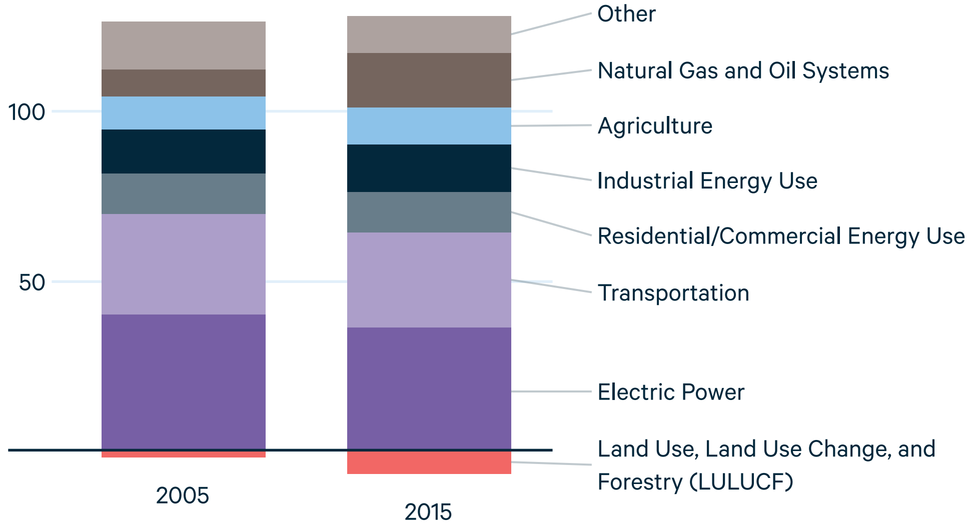
Emissions units: million metric tons of CO_2equivalent (mmtCO_2e)
Source: **Colorado 2015 Greenhouse Gas Inventory Update**

The law's new targets are ambitious—26 percent below 2005 levels by 2025, 50 percent below 2005 levels by 2030, and 90 percent below 2005 levels by 2050—but

5 Source: Colorado Department of Public Health and Environment, 2019. **"Colorado 2015 Greenhouse Gas Inventory Update Including Projections to 2020 & 2030."** Note: In June 2020, the firm Energy+Environmental Economics released "CO GHG Roadmap Scenarios" for the CO AQCC. This document included significant revisions to methane emissions from natural gas and oil systems. For the purpose of this analysis, we use only the official inventory published by the CDPHE but consider the impacts of the revised benchmarks in a sensitivity analysis.

6 The decrease in emissions between 2010 and 2015 can be entirely attributed to a change in land use and forestry sinks, a general category for natural negative emissions that is difficult to estimate and often subject to revision, even at the national level.

Figure 2. Historical Composition of GHG Emissions



Emissions units: million metric tons of CO_2equivalent (mmtCO_2e)
Source: **Colorado 2015 Greenhouse Gas Inventory Update**

are broadly in line with the global emissions pathway the IPCC said would be required to keep global warming at or below 1.5 degrees Celsius (45 percent below 2010 levels by 2030 and net zero by 2050).[7] To meet these targets, the state must reduce annual emissions by nearly 29 mmtCO_2e by 2025 (relative to 2015, the last year data is available), by almost 59 mmtCO_2e by 2030, and by over 108 mmtCO_2e by 2050.

The combustion of fossil fuels is the largest source of GHG emissions globally, nationally, and within Colorado. In Colorado, these emissions from energy use are responsible for 74 percent of net GHG emissions. The electric power and transportation sectors were responsible for 30 and 23 percent of net emissions in Colorado in 2015, respectively, while industrial energy use and buildings (residential and commercial energy use) were responsible for 12 and 10 percent of net emissions in 2015, respectively.[8] The remaining emissions come from non-energy nitrous oxide and methane emissions from the agricultural sector, methane emissions from natural gas and oil systems, and smaller amounts from waste management and industrial processes. Methane emissions from natural gas and oil systems are the only major emissions source that increased substantially between 2005 and 2015, a result of the large increase in oil and gas production in the state during that period.

The size of potential emissions reductions in each sector depends on a variety of technical and economic considerations that determine each sector's marginal

7 International Panel on Climate Change, **"Global Warming of 1.5˚C."** October, 2018.

8 Colorado's emissions inventory does not include emissions attributable to the generation of electricity outside the state that is then imported into the state. Including these emissions would increase the 2005 benchmark level of emissions by about 4 mmtCO_2e.

abatement cost curve—an estimate of the opportunities and costs to reduce emissions each year. The size of potential reductions in each sector also crucially depends on policy choice and market dynamics, as will be discussed further below.

2.2. Existing State Actions to Reduce GHG Emissions

Colorado has already adopted numerous policies to reduce GHG emissions in the future. Notable policies include the adoption of both low- and zero-emission vehicle standards;[9] statute SB19–236, which requires utilities with more than 500,000 customers in Colorado to reduce their emissions from delivered electricity by 80 percent in 2030, relative to 2005 levels;[10] new enhancements in December 2019 to the state's existing regulations on methane emissions from oil and gas operations to require stronger safeguards for low-producing wells and requirements for fixing malfunctioning valves; and AQCC Regulation 22 Part B, which will phase out the use of certain HFC's in air conditioning and refrigeration equipment, aerosol propellants, and foam end-uses. As discussed below, the expected emissions reductions from these policies are insufficient to achieve the 2025 or 2030 targets and additional policies will be required to meet the targets in each year.

Methodology

To evaluate the environmental and economic impacts of potential cap-and-trade programs in Colorado, we use the RFF dynamic regional computable general equilibrium (RFF-DR CGE) model. The RFF-DR CGE model is a dynamic multi-region and multi-industry intertemporal model of the US economy with international trade. Computable General Equilibrium (CGE) models combine detailed economic data with formulas that describe economic behavior to project how an economy will respond to a policy over time. For each policy scenario, the model calculates the changes in the supply and demand of producer and consumer goods by households and firms in each region and the corresponding changes in market-clearing prices. The model is benchmarked to 2015 data, the last year in which all necessary regional data are available. Please see Appendix A for a description of the RFF-DR model.

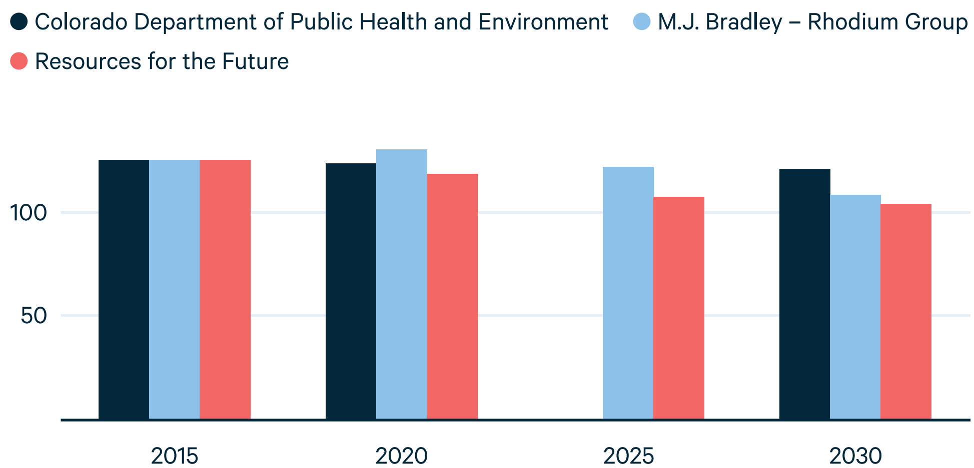
9 The Clean Air Act waiver that allows these standards to be enforced was revoked by the Trump Administration in 2019, a decision that is currently being challenged in court by states, public interest groups, and companies who contend that the Administration lacks authority to withdraw the waiver.

10 Xcel Energy is the only utility that would be covered by the statute.

3. Business-as-Usual Projections

When the state's most recent official inventory was released in 2019, prior to the COVID-19 pandemic, the State of Colorado did not expect to meet its emissions targets under current market conditions and existing federal and state policies. The Colorado Department of Public Health and Environment's (CDPHE) 2019 GHG inventory report projected emissions would be 121 mmtCO_2e by 2030.[11] As noted in its report, however, the tool used to generate these projections utilizes national data and "there are limited provisions for state adjustments to activity data and no provision for state adjustments to emissions factors for future projections."

Figure 3. Colorado GHG Projections, 2025 and 2030



Emissions units: million metric tons of CO_2equivalent (mmtCO_2e)

Alternative projections are more optimistic but still project a significant compliance gap in both 2025 and 2030. Figure 3 displays three projections of Colorado's emissions. The first is from the CDHPE, as described above. The second is from a report by **M.J. Bradley and Associates** that used an adjusted BAU projection from the Rhodium Group's US Climate Service (henceforth MJB-RHG). The third is the business-as-usual projection from the RFF-DR CGE model built specifically for this report.

The overall level of emissions projected in 2030 is remarkably consistent between the MJB-RHG analysis and the RFF-DR model, though the path to reach those levels of emissions differs across models. The differences most likely follow from differences in power sector projections. In the RFF-DR model, 93 percent of the projected BAU change

11 Colorado Department of Public Health and Environment, 2019. **"Colorado 2015 Greenhouse Gas Inventory Update Including Projections to 2020 & 2030."** Note: Exhibit ES-1 includes projections for *gross* greenhouse gas emissions. For comparison to net greenhouse gas emissions projections, we assume the same level of LULUCF negative emissions as in our own BAU projections.

Projecting Colorado's BAU GHG Emissions with the RFF-DR Model

All greenhouse gas emissions by sector are benchmarked to the 2015 CDPHE GHG emissions inventory. Using the Energy Information Administration's (EIA) *Annual Energy Outlook* (AEO) 2020 projections of energy use under current federal and state policies (including the existing policies described above and the planned retirement of 5 coal generating units in Colorado), model parameters are calibrated such that the model can approximately replicate actual and projected changes in energy demand growth by sector (residential, commercial, industrial, transportation, electric power) between 2015–2019, 2019–2025, and 2025–2031. Where possible, projections from the AEO's Mountain region are used for Colorado. Energy use and energy-related carbon dioxide emissions projections have not been updated as a result of the COVID-19 pandemic, though we do consider a COVID-19 GDP sensitivity that adjusts GDP growth in the BAU scenario.

For non-energy-related CO_2 emissions, we assume these emissions are proportional to industrial output in the state. Agricultural and waste management emissions are assumed to be constant over time. Coal mining methane emissions are assumed to be proportional to state coal output. Emissions projections from natural gas and oil systems in Colorado assume both existing and aspirational regulations (unless otherwise noted, all projections are under existing regulations only).* Other emissions, which include non-CO_2 emissions from the residential, commercial, industrial, transportation, and electric power sector as well hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6), are largely assumed to be constant. Expected reductions under Colorado's new HFC regulation are phased in over time.

* See Comments by Environmental Defense Fund and Western Resource Advocates on the Colorado GHG Pollution Roadmap modeling effort ("Roadmap"), May 13, 2020, pp. 6-7. Baseline projections include reductions attributable to the AQCC December 19, 2019 rulemaking and aspirational projections include full implementation of SB19-181.

in emissions for the power sector between 2020 and 2030 occur between 2020 and 2025 (see below for sectoral breakdown of projections). Changes in coal generation are projected to be larger in the first half of the decade than the second half of the decade. This follows directly from the calibration of the RFF-DR baseline to EIA's AEO2020 reference case projection for national fuel prices and regional generation shares conditional on those prices.[12] The changes in coal generation in the RFF-DR model may

12 The electric power sector in Colorado is vertically integrated whereas the model treats electricity markets in all regions as wholesale markets and vertically integrated firms may not be as price responsive as firms in the RFF-DR model. Future analysis could consider altering key substitutions of elasticity to test the sensitivity of BAU and policy emissions to this important set of parameters.

represent either retirements of additional coal units (beyond the ones slated to retire) or a change in the utilization rate of existing coal units based on economic conditions including the availability of natural gas and declining costs for renewables in the state (although dispatch and retirement decisions particularly in vertically-integrated power sectors can often be affected by other factors).[13]

Table 1 compares the composition of emissions from the CDPHE and RFF-DR BAU projections, with 2015 emissions for comparison (detailed emissions projections from MJB-RHG are not publicly available).[14] The RFF-DR projections are lower than CDPHE projections for both CO_2 and non-CO_2 emissions. For non-CO_2 emissions, the most noticeable difference is in coal mining methane emissions. As noted in the previous section, the RFF-DR model projects coal mining emissions to fall with the continued decline in coal mining output. For CO_2 emissions, RFF-DR and CDPHE differ most significantly on transportation and electric power emissions, most likely reflecting the inclusion of state policies that were not included in the CDPHE analysis due to the methodology used in their projections, though it is also possible that more fundamental assumptions such as overall electricity demand and vehicle miles traveled drive some of the differences. It is beyond the scope of this report to decompose the differences in BAU emissions.

13 As a robustness check, we also created a BAU projection of electric generation emissions in Colorado using the Haiku electricity model. That exercise also finds steep declines in coal generation emissions between 2020 and 2030, with a majority of those reductions occurring prior to 2026.

14 Following the CDPHE official inventory, emissions from imported electricity generation are not included in the RFF-DR projected BAU emissions. Approximately 10 percent of Colorado's electricity is produced outside the state and the CDPHE report calculates that Colorado's demand for imported electricity accounted for about 3 mmtCO_2e of additional emissions in 2015.

Table 1. Detailed Reference Case Projections of Colorado Greenhouse Gas Emissions in 2030

	2015	2030	
	Historical	**CDPHE**	**RFF-DR**
GHG Emissions (mmtCO_2e)			
Energy-Related CO_2 Emissions	89.5	81.1	71.5
Other CO_2 Emissions	1.5	2.2	2.0
Non-CO_2 Emissions	36.0	39.1	32.1
LULUCF	-6.5	-1.9	-1.9
Total (Net)	120.4	120.5	103.7
Energy-Related CO_2 Emissions (mmtCO_2)			
Residential	7.5	8.6	7.2
Commercial	4.0	3.3	4.3
Industrial	14.0	14.0	17.9
Transportation	27.8	29.7	25.8
Electric Power	36.1	25.4	16.3
Total	89.5	81.1	71.5
Non-CO_2 Emissions			
Agriculture	10.7	9.1	10.7
Waste Management	4.2	5.9	4.2
Coal Mining	1.9	6.6	1.0
Natural Gas and Oil Systems	15.6	15.3	13.7
Other	3.7	2.3	2.6
Total	**36.0**	**39.1**	**32.1**

Notes: Projections for energy-related CO_2 emissions from RFF-DR Colorado baseline. See text for description of assumptions for non-energy-related CO_2 emissions.

4. Economy-Wide Cap-and-Trade Scenarios

4.1. Adding Flexibility to Cap-and-Trade Programs

There are myriad design options for cap-and-trade programs devised to limit greenhouse gas emissions. The most basic policy design options include *coverage*: what gases to include and what sectors to include; the *point of regulation:* what entities in the supply chain are legally responsible for submitting allowances; the *allocation of allowances* across covered entities: do firms purchase allowances at quarterly auctions (and how is the value from the auction distributed) or are firms allocated allowances by the regulator (to reduce consumer costs in regulated industries or to provide a production incentive to protect Colorado business from unfair competition); and perhaps most importantly, the program's *stringency:* how many allowances are put into circulation each year (which represents the "pollution limit" or total allowable emissions).

Economic research has also shown the importance of including design provisions that increase the flexibility of when and where emissions reductions are achieved.[15] Allowing firms to purchase current period allowances and submit them in future years (*banking*) or promise to purchase future allowances and submit them in the current year (*borrowing*) introduces intertemporal flexibility into a cap-and-trade system. When banking and borrowing is allowed, emissions in any specific year may be greater or less than the number of allowances issued in that year, but over the compliance period, the cumulative number of allowances and covered emissions must be balanced.[16] This gives firms more flexibility in determining when they reduce their emissions.[17]

To encourage low-cost emissions reductions at sources not covered by the cap, a cap-and-trade program can provide an economic incentive to capture these emissions reductions through a carbon offsets program. Carbon offsets are a key part of many existing cap-and-trade programs. For example, California's Western Climate Initiative

15 **See, for example, Burtraw, Farrell, Goulder, and Peterman (2006)**.

16 Borrowing should be limited to prevent moral hazard issues (firms will borrow allowances and then lobby for the program to be dismantled before the payment is due) and to prevent adverse selection issues (firms that acquire a debt of borrowed allowances may be firms more likely to go out of business). In our analysis, borrowing does not occur as the cost of reducing emissions to meet long-run goals is likely to be much higher than the cost of moderately increasing short-run emissions reductions.

17 Additionally, global climate damages from each ton of carbon dioxide equivalent are a function of the cumulative stock of greenhouse gases in the atmosphere and not the annual flow of emissions.

Banking: An Example

In a scenario in which today's compliance costs are relatively low and future compliance costs are expected to be much higher, perhaps because of expected increasing stringency of an emissions cap, a forward-looking firm with access to credit markets could reduce its overall costs of compliance across all periods by borrowing money and using that money to invest in emissions reductions today when they are relatively cheap and acquire allowances to use in future periods when they become relatively more expensive. This type of behavior would increase demand for allowances today, increasing their price, and providing more incentives to all firms to reduce their emissions more today than in the absence of banking. These incentives created by banking tend to relieve program compliance costs and reduce the likelihood of high future prices. A related consequence is additional reductions in criteria air pollutants in the near term.

Colorado's emissions reductions targets increase quite steeply between 2025 and 2030 and compliance costs in 2030 are likely to be quite high in the absence of banking.

allows emitters to submit offset credits in lieu of allowances to cover emissions.[18] California's offset system provides cost-effective emissions reductions from natural and working lands, though theoretically offsets could come from any uncovered source of emissions within or outside the state (from reductions in waste management methane emissions, for example). The Regional Greenhouse Gas Initiative (RGGI), that covers power sector emissions in ten Northeast states, also allows firms to submit offsets (up to 3.3 percent of allowances) and all offset projects must be located within one or more of the RGGI states that award the CO_2 offset.[19]

There are political, economic, and administrative benefits of linking programs across jurisdictions. On a political level, linking programs signals a common effort to reduce emissions. The incremental alignment of program elements and the prospect of formal linking also contribute a political benefit by signaling progress toward greater levels of cooperation necessary to achieve significant scale across jurisdictions to meaningfully confront the climate challenge.

18 California originally limited offsets to 8 percent of overall allowance through 2020 before reducing the limit to 4 percent from 2021–2025 and then increasing the limit back to 6 percent from 2025–2030.

19 RGGI offsets can be awarded to projects within five categories: landfill methane capture, reductions in sulfur hexafluoride emissions from electricity transmission and distribution, forestry and afforestation projects that increase and/or conserve forest carbon stocks, increases in end-use efficiency in existing or new commercial or residential buildings, and avoided agricultural methane.

What are Offsets and What are their Benefits?

Offset programs are often introduced as cost-containment provisions. Offsets are emissions reductions in non-regulated sectors or carbon dioxide removal projects (typically from land and forestry). Entities that can verify emissions reductions or removal can sell their certified offset to regulated firms, who can then submit that offset in lieu of an allowance. The benefits of offsets are that they allow for the potential for reductions (or removal) to occur outside of the regulated sectors, where reductions (or removal) may be less expensive than reductions in regulated firms. Offset projects may also provide ancillary benefits to the local environment. In California, for example, offset credits may be awarded to ranchers for reducing livestock methane emissions, which would also reduce ground-level ozone.

In practice, it can be difficult to ensure the quality of offset projects. For this reason, most cap-and-trade programs limit the use of offsets and have strict protocols for approving projects. Colorado could build on protocols developed in either California or the RGGI program to help ensure the additionality and permanence of these offset reductions.

Economically, formal linking allows for the flexibility to reduce emissions across space by changing the distribution of mitigation activities across jurisdictions and allows for overall reductions to be achieved at the lowest possible cost. Further, it broadens the portfolio of emissions reduction options and thereby helps buffer carbon markets against uncertainties that affect cost, such as patterns of economic activity and weather. Formal linking also allows allowance markets to exploit differences in technology and resource costs across trading programs. In addition, both formal and incremental linking help reduce the costs for regulated business by reducing the uncertainty they face in the development of different trading programs. They also reduce the problem of leakage of economic activity to jurisdictions that do not regulate emissions in the same way. These features contribute to lower overall mitigation costs that might enable individual trading programs to commit to more ambitious emissions reductions.

Linking also has administrative benefits. The process of linking enhances the opportunity for regulators to share best practices in program administration including procedures for measurement, reporting, and verification of emissions and protocols for allowance tracking systems as well as overall program design. Linking, insofar as it leads to alignment in administration and design, might streamline compliance and offer reduced administrative costs for businesses operating in both jurisdictions. It may also streamline the administrative operations among multiple jurisdictions by collecting those activities in a single operation.

4.2. Modeling Cap-and-Trade Programs in Colorado

We evaluate two different cap-and-trade programs in Colorado. The first policy is a cap-and-trade program for Colorado designed to meet the cumulative emissions target set forth by the Climate Action Plan. Following the Western Climate Initiative example, cost containment measures include both banking of allowances and a certified offset program (limited to 6 percent of total allowances). The cap is on energy-related carbon dioxide emissions only (industrial process carbon dioxide emissions and all non-CO_2 GHG emissions are exempt) and allowances are freely allocated to the points of regulation.[20] Allowance allocation is one of the most important features in the design of a cap-and-trade program. This assumption is a placeholder and approaches to allocation need to be studied further as allowance allocation can be used to achieve ancillary goals such as equity, leakage avoidance, and political feasibility.

In the second policy, the Colorado is a direct participant in the Western Climate Initiative. Colorado would issue its own allowances but Colorado firms can demonstrate compliance by surrendering allowances or offset credits issued by any WCI participating jurisdiction, subject to state-specific limits on offset use. The Western Climate Initiative has also developed a number of guidelines addressing accounting rules, treatment of fuels movement, etc. that Colorado would otherwise have to develop under its own program. An additional feature of the regional program is a minimum ("reserve") price in the quarterly auction below which allowances will not be sold. This feature has served to limit supply when demand for allowances has been low, thereby maintaining a minimum allowance price in the market.

The analysis that follows is meant to be primarily illustrative of different cap-and-trade programs designed to meet Colorado's emissions targets. The design is not meant to be suggestive of what a Colorado program *should* look like. For example, due to modeling constraints, the policies do not cover carbon dioxide emissions from industrial processes or fluorinated gases, two types of emissions that could feasibly be covered by a cap-and-trade program. The model also does not consider the impact of non-inframarginal transfers of allowances, such as output-based allocation for energy-intensive trade-exposed industries or the use of allowance revenue to mitigate price impacts for consumers.[21] Allowance allocation is one of the most important features of program design.

20 Alternatively, allowances could be conditionally allocated but not usable for compliance unless they are sold on consignment at auction, with the revenues directed to the owners of the allowances. This approach would enable the state to capture the advantages of an auction including price discovery, ensuring allowances go to their highest valued use, and the introduction of a price floor and other supply restrictions to manage cost at various price points, as is implemented in the other North American carbon markets.

21 The inclusion of output-based allocation or using revenue to mitigate price impacts for consumers are distortionary policies that raise the overall cost of compliance by reducing incentives to reduce emissions through less production or energy demand, respectively. These design elements, however, do shift the burden away from energy-intensive trade-exposed industries and households, respectively, and could be considered for political reasons.

There is also inherent uncertainty in any forecast of future energy demand and greenhouse gas emissions, especially under carbon pricing scenarios. The point estimates projected here are not meant as precise forecasts.

The policies modeled have the following features:

- Allowances are required for carbon dioxide emissions from the combustion of all fossil fuels (coal, petroleum products, natural gas) combusted within Colorado beginning in 2021.
- Carbon dioxide emissions from industrial processes and non-carbon dioxide GHG emissions are exempt.
- The point of regulation is electricity generators, industrial facility operators, and fuel distributors. For modeling simplicity and to be consistent with the state's definition of emissions, imports of electricity are not covered under the program in these modeling scenarios.[22]
- The cap on carbon dioxide emissions is set, given assumptions on uncovered emissions, to meet the state's target in 2025 and 2030. Specifically, the annual GHG targets are set by linearly interpolating between 2015 inventory levels and 2025 and 2030 targets. Non-covered emissions are assumed to be constant at BAU levels. The annual cap on covered energy-related carbon dioxide emissions are set such that the annual GHG target is met each year. Table B.1 in Appendix B reports both the annual GHG targets and the annual caps on energy-related carbon dioxide emissions.
- Firms are allowed to bank allowances. Emissions are allowed to differ from the annual target each period but cumulative emissions between 2021 and 2030 cannot exceed the overall emissions budget. As a consequence of banking, the allowance price in the model rises annually at the annual rate of interest (4 percent) in the CO-only program.
- Firms may submit certified offsets in lieu of allowances. The overall cap on offsets is set to 6 percent of total submitted allowances.
- When allowances are freely allocated to points of regulation, they are distributed in proportion to historical emissions. The modeling assumes that firms are not allowed to use allowances to mitigate price impacts for consumers.

22 There are issues associated with measuring the source and emissions intensity of electricity serving Colorado consumption that could be addressed through regulatory reforms including increased participation in organized power markets. However, the model restricts an increase in imported electricity that would constitute leakage of emissions from under the state cap to sources out of state. Regulatory practice and incentives facing the state's utilities justify the expectation that generation shifts that are realized to reduce electricity sector emissions are most likely to be achieved through investments in generation resources in the state.

- Under the Western Climate Initiative scenario, prices are assumed to follow the prescribed price floor.[23] The price in 2021 is $17.56 (in $2020) and rises at five percent above inflation each year.

4.3. Projections for Cap-and-Trade Programs in Colorado

4.3.1. Emissions

Table 2 displays the change in emissions under both the CO-only and WCI-linked cap-and-trade programs in 2025 and 2030. Under the CO-only program, net GHG emissions fall from 103.7 mmtCO_2e in 2030 under BAU to 80.1 mmtCO_2e. Emissions in 2025 are lower than the state's target (91 mmtCO_2e) but emissions in 2030 are higher than the state's target (61.5 mmtCO_2e): cumulative emissions reductions over the decade are consistent with the state's targets but firms choose to abate more in the early years of the policy and less in the later years due to the high costs of deep reductions and the ability to bank allowances (and a similar dynamic would likely occur if the program were extended past 2030 and banking between 2030 and 2050 were allowed). Emissions fall the most in the electric power sector, reflecting low-cost abatement options in the sector. Coal emissions from the power sector are basically eliminated by 2030 (99 percent reduction in emissions from coal-fired generation). Emissions from natural gas generation initially increase under the policy as a replacement for coal generation but are then replaced by increased solar and wind generation between 2025 and 2030. Energy-related carbon dioxide emissions from the industrial sector are responsible for the second largest source of reductions whereas there are relatively small reductions from the residential, commercial, and transportation sectors, reflecting the relatively high cost of reducing emissions in those sectors.

Under the WCI-program, firms can submit compliance instruments (including allowances or offsets) issued by Colorado or issued by California and/or Quebec. This flexibility leads to a lower allowance price (assumed to be equal to the program's price floor in all years) and higher in-state emissions in all covered sectors. Overall net GHG emissions are 87.1 mmtCO_2e in 2030; the difference in emissions from the CO-only program represent reductions secured from other WCI jurisdictions where reductions are less costly. With its relatively low costs of abatement, there are nonetheless substantial reductions in the electric power sector in Colorado under the WCI-linked program.

23 In five quarterly auctions in 2016–2017 and in the May 2020 auction the settlement price of the WCI auctions conducted by California and Quebec has been at the auction's price minimum. In May 2020, during the COVID-19 pandemic, over 30 million allowances offered for sale were unsold. In other quarterly auctions the price has been only slightly above the price minimum. Evidence also suggests that over 200 million allowances are currently being banked for future use. We find it very unlikely that Colorado's participation would substantially impact overall allowance demand within the WCI.

Table 2. Emissions Projections under Alternative Cap-and-Trade Programs

	CO-Only Program		WCI-Linked	
	2025	2030	2025	2030
GHG Emissions (mmtCO_2e)				
Energy-Related CO_2 Emissions	54.3	50.8	61.3	58.2
Other CO_2 Emissions	1.9	2.1	1.9	2.1
BAU Non-CO_2 Emissions	34.2	32.2	34.4	32.2
BAU LULUCF	-1.9	-1.9	-1.9	-1.9
Offsets	-3.3	-3.0	-3.7	-3.5
Total (Net)	**85.2**	**80.1**	**92.0**	**87.1**
Energy-Related CO_2 Emissions (mmtCO_2)				
Residential	6.5	6.2	7.0	6.8
Commercial	4.0	4.0	4.2	4.2
Industrial	12.7	12.9	15.1	15.5
Transportation	24.8	23.5	26.0	24.9
Electric Power	6.3	4.2	9.0	6.8
Total	**54.3**	**50.8**	**61.3**	**58.2**

Both programs introduce a limited offset program, with offsets allowed up to 6 percent of total allowances submitted in each year.[24] This contributes modest reductions in Colorado's GHG emissions through reductions outside of the covered emissions in natural and working lands.

4.3.2. Costs and Benefits

An economy-wide cap-and-trade program has both costs and benefits and those costs and benefits can vary widely by program design. There are also many different ways to measure the cost of the policy. The allowance price captures the marginal cost of an additional reduction; the higher the allowance price, the higher the cost of compliance.

24 The model does not explicitly model offset supply curves by sector but assumes that all offsets are created within Colorado.

Table 3. Annual Abatement Cost Estimates

Year	CO-Only Program	WCI-Linked Program
2021	$513	$108
2022	$531	$114
2023	$549	$119
2024	$562	$124
2025	$575	$156
2026	$609	$136
2027	$644	$144
2028	$684	$157
2029	$726	$168
2030	$772	$184
Cumulative (undiscounted)	**$6,165**	**$1,410**

Under the CO-only program, the allowance price is about $75 in 2030 (in $2020), reflecting the cost of reducing an additional ton of emissions. Because this marginal cost is increasing in the level of reductions each period, the price would be much higher if banking were not allowed. With the flexibility of importing allowances from the other WCI jurisdictions, the allowance price in 2030 under the WCI-linked program is expected to be much more modest, at about $27 (in $2020).

A rough approximation of total abatement costs is to multiply the allowance price by emissions reductions in the covered sectors and divide by two.[25] Table 3 displays the annual abatement cost estimates from 2021 to 2030 (all in $2020). For the CO-only program, overall abatement costs in 2030 are $770 million and cumulative (undiscounted) costs are $6.2 billion; for the WCI-linked program, overall abatement costs in 2030 are about $180 million and cumulative (undiscounted) costs are $1.4 billion. The difference reflects the additional costs of achieving all reductions from covered sectors within the state of Colorado compared to achieving some of those reductions outside the state.

GDP is a widely used measure of economic activity that captures the total value of goods and services produced within a jurisdiction; changes in inflation-adjusted GDP

25 If the marginal abatement cost curve were linear between zero and the allowance price, this calculation would hold precisely. The actual total abatement cost of the policy is the integral beneath the marginal abatement cost curve. Because the marginal abatement cost curves are actually convex, this approximation overstates the overall abatement costs.

Table 4. Allowance Prices, Costs, and Benefits under Alternative Cap-and-Trade Programs

	CO-Only Program		WCI-Linked Program	
	2025	2030	2025	2030
Allowance Price ($2020)	$61.18	$74.43	$21.35	$27.24
Change in GDP (million $2020)	-$1,477	-$2,380	-$801	-$1,255
Climate Benefits (million $2020)	$1,069	$1,283	$1,069	$1,283
Local Pollution Benefits (million $2020)				
Sulfur Dioxide	$265–$605	$232–$531	$220–$503	$203–$465
Nitrogen Oxide	$230–$519	$235–$532	$121–$274	$127–$288
$PM_{2.5}$	$342–$780	$381–$869	$143–$328	$169–$385
Net Benefits (million $2020)	$429–$1495	–$249–$835	$752–$1373	$527–$1166

approximate overall policy costs.[26] GDP could increase or decrease in response to an economy-wide cap-and-trade program. If, for example, oil and natural gas drilling decreases as a response to the policy, the change in output from these industries will be reflected as a decrease in GDP. Similarly, if industry shifts production from Colorado to neighboring states, GDP will decrease. Alternatively, GDP will increase both with the construction of new solar and wind generation capacity and the operation of those new generators over time. Likewise, GDP will increase if consumers substitute their spending on imported products (such as refined fuels) for spending on locally produced goods.

Our modeling projects that GDP growth will marginally decline in response to both the CO-only and WRI-linked cap-and-trade programs.[27] With less flexibility and more in-state emissions reductions, the GDP loss in the CO-only program is larger than the loss under the WRI-linked program. And while these losses may seem large, GDP is projected to be about $466 billion ($2020) in 2030 in our BAU projections: the GDP loss is about 0.5 percent of BAU GDP under the CO-only program and 0.3 percent of BAU GDP under the WRI-linked program.[28]

26 GDP is an imperfect measure of economic activity because it fails to measure the value of most non-market goods and services (that is, goods and services that are not bought and sold), even though they have substantial value. For example, childcare provided by daycare centers are included in GDP but childcare provided by family members are not included.

27 Metcalf and Stock (2020) present empirical evidence from European carbon pricing schemes, including the EU ETS, and find no robust evidence of a negative effect on employment or GDP growth.

28 The GDP loss estimate for the WRI-linked program includes the lost allowance value that is transferred to other jurisdictions when their allowances are purchased. This lost

The economy-wide cap-and-trade program produces environmental benefits that are not captured in GDP including climate-related benefits from reduced GHG emissions and benefits from reductions in local criteria air pollutants that are harmful to human health.

Climate benefits are quantified using a measure known as the Social Cost of Carbon (SCC). The SCC measures the damages, in dollars, of emitting an additional ton of carbon dioxide into the atmosphere. There is significant debate over the value of the SCC, with much of the focus on the choice of the discount rate used to evaluate the cost of future damages today and whether to measure global benefits or only national or subnational benefits.

In this analysis, we use an SCC of $51.93 in 2020 (in 2020$) and growing to $61.83 in 2030 (in 2020$), reflecting the average SCC, using a 3 percent discount rate, from the Obama administration's Interagency Working Group's 2016 update.[29] Using these estimates for the SCC, the estimated climate benefits are valued at $1.28 billion ($2020) in 2030 under both policies. The CO-only policy delivers higher in-state climate benefits than the WCI-linked program because it has more in-state reductions but the WCI-linked program also includes the benefits of reductions from other jurisdictions. The Obama 2016 SCC estimates are also likely to be an underestimate of the true benefits of reducing an additional ton of emissions into the atmosphere, as these models generally do not account for tipping points and impacts such as loss of biological diversity, ocean acidification, and the bleaching of coral reefs are not included due to the difficulty of quantifying the monetary value of these damages.

Reductions in local criteria air pollutants can substantially improve human health for residents of Colorado. Unlike the climate benefits which are realized globally, the benefits of reduced air pollution directly benefits the communities where emissions reductions occur. Using estimates from the US EPA's Office of Air Quality Planning and Standards, we quantify the benefits of reduced morbidity and mortality from a reduction of a single ton of $PM_{2.5}$ in the atmosphere ($PM_{2.5}$ can be emitted directly or created indirectly through chemical transformations of SO_2 or NO_x emissions) from 17 sectors (EPA 2018a).[30] The estimated combined benefits of reduced $PM_{2.5}$ through

allowance value amounts to about $150 million in 2025 and $200 million in 2030.

29 Further, we assume that Coloradoans care about global well-being and therefore we use estimates for the global social cost of carbon (that is, the total damage to the entire world of emitting an additional ton of carbon). The direct subnational and national impacts will vary tremendously. Even in Colorado, the effect of climate change will vary across businesses and households. Agriculture may experience longer growing seasons, while ski resort operations may be forced to shut down during shorter winters. It is beyond the scope of this report to project impacts of climate change within Colorado.

30 The health benefits here are only those related to $PM_{2.5}$ pollution (direct and indirect). The benefit estimates do not quantify reductions in other forms of local air pollution created through emissions of local air pollutants. The lower estimate represents the Krewski et al. (2009) mortality estimates and the upper bound represents the Lepeule

direct $PM_{2.5}$ emissions and SO_2 and NO_x emissions are nearly $500 million annually under the WRI-linked program and over $800 million under the CO-only program using the more conservative benefit per ton estimates; the combined benefits are over $1.1 billion annually under the WRI-linked program and over $1.9 billion under the CO-only program using the higher benefit per ton estimates. The CO-only program delivers more local health benefits because it requires more in-state reductions in the combustion of fossil fuels.

Comparing only the quantified environmental benefits of both policies to the projected GDP loss, the CO-only program produces positive net benefits in 2025 and the WRI-linked program produces net benefits in both 2025 and 2030 when using the conservative benefit per ton estimates for local pollution benefits; the net benefits are positive in both programs and both 2025 and 2030 when using the higher benefit per ton estimates. As shown in Table B.2, cumulative (undiscounted) net benefits are between $3.4 billion and $14.5 billion for the CO-only program and between $7.4 and $13.9 billion under the WRI-linked program (in $2020). Of course, using a higher (lower) SCC would substantially increase (decrease) these net benefit estimates, and quantifying other environmental benefits would also increase these estimates.

4.3.3. Criteria Air Pollutants

As discussed above, changes in local criteria air pollutants provide immediate benefits to Colorado residents and we quantified the benefits of reduced $PM_{2.5}$ (direct and indirect through SO_2 or NO_x emissions). Table 5 displays the complete Colorado inventory of criteria air pollutants—carbon monoxide (CO), nitrogen oxide (NO_x), particulate matter (PM_{10} and $PM_{2.5}$), sulfur dioxide (SO_2), volatile organic compounds (VOCs) and ammonia (NH_3)—from the EPA's 2017 National Emissions Inventory along with reference case projections and the percent change in emissions under the two cap-and-trade program scenarios.[31] Sulfur dioxide emissions are primarily associated with coal generation and the significant decrease in coal generation in response to these policies significantly lowers these emissions. The policies have smaller effects on other types of criteria air pollutants such as volatile organic compounds and ammonia, which are not typically associated with fuel combustion. The change in $PM_{2.5}$ emissions is 6–7 percent of baseline emissions (about 800–900 metric tons) under the CO-only program and yields significant health benefits as described previously.

The health benefits of these reductions depend on the source and the location of the emissions, as well as the ambient air concentrations and the weather patterns

et al. (2012) mortality estimates (both using a three percent discount rate) and apply the 2020 estimates for all years (does not account for annual increases in benefit estimates). See Table B.3 for annual and cumulative projections of benefits.

31 The model uses constant emissions factors to map industry outputs, industry inputs, and household consumption in the RFF-DR model to 60 different emissions sources in the National Emissions Inventory. See Table B.3 for projections in the level change in local air pollutants.

Table 5. Reference Case Criteria Air Pollutants and Projected Changes under Cap-and-Trade Programs

	Historical Inventory	Reference Case Projections		CO-Only Program		WCI-Linked Program	
	1000 metric tons			Percent Change from Reference Case			
	2017	2025	2030	2025	2030	2025	2030
Criteria Air Pollutant							
Carbon Monoxide	711.6	607.6	566.7	-10.9%	-12.8%	-4.4%	-5.4%
Nitrogen Oxide	172.4	131.1	119.9	-17.5%	-19.2%	-10.0%	-11.2%
PM_{10}	22.2	20.7	20.2	-5.3%	-6.2%	-2.2%	-2.7%
$PM_{2.5}$	14.2	13.2	12.9	-6.0%	-6.9%	-2.5%	-3.0%
Sulfur Dioxide	19.2	9.2	8.2	-60.7%	-59.2%	-51.5%	-53.2%
Volatile Organic Compounds	202.3	182.7	165.5	-6.5%	-7.9%	-2.6%	-3.3%
Ammonia	3.7	2.9	2.6	-7.6%	-9.0%	-2.9%	-3.6%

Note: Includes only criteria air pollutants from fuel combustion (stationary and mobile) and industrial processes.

that disperse the pollutants across the state and its neighbors. Hence it is especially difficult to quantify the monetary values of most of these emissions reductions and why we only quantify one type of benefits above. Because these estimates do not include the health benefits of reduced CO, PM_{10}, VOCs and NH_3 or the non-$PM_{2.5}$ benefits of reduced NO_x (a precursor to tropospheric ozone pollution) or SO_2 (a contributor to acid rain), the local air benefit estimates clearly understate the overall benefits of reductions in criteria air pollutants from the cap-and-trade scenarios considered in this analysis.

4.4. Alternative Program Design

4.4.1. Policy Coverage

The cap-and-trade programs analyzed above were meant to be illustrative examples of the potential impacts of such policies in Colorado. For modeling purposes, we made a number of simplifying assumptions on policy design. For example, we assumed that industrial process carbon dioxide emissions, that represented only 1.2 percent of net GHG emissions in 2015, were not included in the policy. Because most of these types of emissions are caused by processes that are fundamental to the production of a particular good (e.g., carbon dioxide emissions caused by the chemical process used to produce cement), emissions reductions in these sectors are likely to be expensive and including them would most likely require additional reductions from sectors already covered and a (very slight) increase in overall program cost. Further, trade-exposed facilities may be tempted to leave Colorado for neighboring states if the policy were to become onerous for business. Free allocation may keep firms in the state if they lose free allowances when moving and output-based allocation could be used to provide a production incentive for firms that could further prevent the reduction in industrial output affected by the coverage of industrial process carbon dioxide emissions. Colorado's Air Pollution Control Act contemplates this approach, and provides direction to regulators designed to mitigate such concerns.[32]

Imported electricity is also not covered in the policy. In 2015, approximately 10 percent of Colorado's electricity was generated in other states. If Colorado were to cover imported electricity, we anticipate slightly higher electricity prices and modest reductions in emissions associated with imported electricity relative to our central case policies. As a result, we predict only a relatively marginal change in the modeling results if imported electricity were to be covered.[33]

4.4.2. Allowance Allocation

The analysis also assumed that all allowances were allocated for free to points of regulation and that this allowance value was not used to lower the impact on consumer prices. In California, allocation of allowance to investor-owned utilities must be used "for the benefit of ratepayers" but specifically precludes these utilities to reduce rates. Publicly-owned utilities, however, are allowed to use free allowances for compliance if they own fossil generators and, in this case, customers don't see an increase in rates (or see a smaller increase in rates). Given the size of the California investor-owned utilities, most consumers do not see reductions in their rates. The allowance value is instead used to fund energy efficiency programs and to fund the climate dividend (uniform per customer account rebates that appear on bills every six months). These dividends are designed to protect households from the expenditure change associated with pricing carbon in the electricity sector while preserving the change in the marginal price of energy so households still have an incentive to reduce their energy use.

If allowance value were used to reduce consumer price impacts, the incentive for households to reduce their demand of electricity and natural gas would be moderated. All else equal, this makes it harder to achieve an emissions target and would increase the market price of allowances under a cap-and-trade program by requiring more

32 Colo. Rev. Stat. § 25-7-105(1)(e)(IX)

33 We recommend future research on alternative schemes to cover imported electricity under the cap.

Table 6. CO-only Cap-and-Trade Program under Alternative Assumptions

	Alternative Natural Gas and Oil System Assumptions		Alternative Offset Cap		COVID-19 GDP Sensitivity		Alternative Emissions Inventory	
	2025	2030	2025	2030	2025	2030	2025	2030
GHG Emissions ($mmtCO_2e$)								
Energy-Related CO_2 Emissions	58.2	55.1	53.2	48.8	54.3	51.1	55.6	52.3
Other CO_2 Emissions	1.9	2.1	1.9	2.1	1.9	2.1	1.9	2.1
BAU Non-CO_2 Emissions	29.7	28.2	34.2	32.2	34.2	32.2	42.4	32.9
BAU LULUCF	-1.9	-1.9	-1.9	-1.9	-1.9	-1.9	-1.9	-1.9
Offsets	-3.5	-3.3	-1.6	-1.5	-3.3	-3.1	-3.3	-3.1
Total (Net)	**84.5**	**80.2**	**85.8**	**79.7**	**85.2**	**80.4**	**94.8**	**82.3**
Energy-Related CO_2 Emissions ($mmtCO_2$)								
Residential	6.8	6.6	6.2	6.0	6.4	6.2	6.6	6.4
Commercial	4.1	4.1	3.9	3.9	3.9	3.9	4.0	4.0
Industrial	14.1	14.5	12.0	12.2	12.9	13.2	13.2	13.4
Transportation	25.6	24.4	24.4	23.1	24.4	23.2	25.1	23.8
Electric Power	7.6	5.6	6.7	3.6	6.6	4.6	6.7	4.6
Total	**58.2**	**55.1**	**53.2**	**48.8**	**54.3**	**51.1**	**55.6**	**52.3**
Allowance Price ($2020)	$35.61	$43.32	$76.14	$92.63	$49.45	$60.17	$51.52	$62.68
Change in GDP (million $2020)	-$963	-$1,531	-$1,520	-$2,771	-$1,214	-$1,943	-$1,292	-$2,070
Climate Benefits ($million 2020)	$898	$1,076	$1,163	$1,449	$1,005	$1,205	$994	$1,192
Local Pollution Benefits (million $2020)								
Sulfur Dioxide	$563	$500	$618	$543	$590	$519	$593	$522
Nitrogen Oxide	$376	$384	$593	$604	$458	$469	$469	$480
$PM_{2.5}$	$507	$570	$927	$1,017	$662	$740	$683	$764
Net Benefits ($million 2020)	$1,380	$999	$1,781	$842	$1,501	$990	$1,448	$888

reductions from other sectors. However, this demand-side channel is not a significant source of emissions reductions in our model and our results would probably not change significantly if some of the allowance value received by utilities were used to offset changes in consumer rates.

Alternatively, the state could allocate zero allowances to firms, auction all allowances, and use the revenue to finance dividends and/or reductions in other taxes. Given the assumption on inframarginal allowance allocation to firms, the results here would largely be unchanged if a dividend approach were used, though it would change how the overall costs were distributed between firms and households. If revenues were used to reduce other taxes, the overall costs of the policy would fall. See Goulder and Hafstead (2017) for a discussion on revenue-neutral recycling options in the context of national policies.

4.4.3. Start Date

The policy in this analysis is implemented in 2021. If due to logistical constraints a cap-and-trade program for Colorado could not be implemented until 2022 or 2023, the policy would effectively become more stringent as there is less time to meet the 2025 and 2030 targets. This would lead to higher costs and remove the flexibility of achieving emissions reductions in 2021 (and 2022) and applying those reductions to the cap in later years through banking.

4.5. Sensitivity Analysis for Projections

As discussed previously, our modeling projections are sensitive to a number of assumptions. In this section, we test the sensitivity of the CO-only program projections to assumptions on uncovered methane emissions, the level of the offset cap, and changes in GDP projections due to the COVID-19 pandemic, and Colorado GHG Roadmap benchmark emissions revisions.

4.5.1. Alternative Natural Gas and Oil System Assumptions

To construct the cap for energy-related CO_2 emissions, we assumed the level of uncovered emissions and set the cap such that total GHG emissions would not exceed the state's GHG targets. This method is sensitive to assumptions of the trajectory of uncovered emissions over time. If, for example, we assumed that methane emissions from natural gas and oil systems would fall more aggressively over time (perhaps in response to future regulations), then the cap on energy-related CO_2 would not have to be as stringent. Table 5 presents results on emissions projections and the associated costs and benefits under a scenario that assumes methane emissions using alternative natural gas and oil system assumptions. Specifically, we assume that these emissions follow an "aspirational" scenario and as a result there is a looser cap set on energy-related CO_2 emissions.[34] Compared to the CO-only scenario, total net GHG emissions are essentially identical, by design, but energy-related CO_2 emissions are about 5 mmt higher in 2030 due to the less stringent cap. The allowance price is therefore also lower under this scenario than the CO-only scenario and the associated GDP costs are also lower and net benefits are higher (note: these estimates do not include the costs and benefits of potential policies on methane required to achieve the aspirational methane scenario).[35]

4.5.2. Alternative Offset Cap Assumptions

The central case CO-only policy analyzed in the previous section included an offset program with a cap on offsets equal to 6 percent of overall allowances. Offsets can potentially help contain compliance costs by allowing for emissions reductions in uncovered sectors to replace emissions reductions in covered sectors. To demonstrate the importance of the flexibility offsets add to the cap-and-trade program, we consider an alternative CO-only program that limits offsets to 3 percent of program allowances. Under this program, more reductions need to come from the covered sectors, increasing the allowance price in 2030 from $75 to $93 and increasing the GDP loss by 16 percent, relative to the central case policy with more offsets.

4.5.3. COVID-19 GDP Growth Rate Assumptions

The ongoing COVID-19 pandemic has led to increased uncertainty in the expected level of economic activity this year and beyond into the next decade. As emissions projections depend substantially on GDP projections, different recovery scenarios have very different implications for both BAU emissions and the cost of a cap-and-trade program to achieve certain levels of emissions. There is no consensus on what the COVID-19 pandemic will do to GDP forecasts and the **shape of the recovery** will likely depend on a number of factors. In a V-shaped recovery, economic activity quickly returns to pre-pandemic baselines. If this were to occur, the pandemic would have no impact on long-run economic activity. In an L-shaped recovery, there is a permanent drop in economic activity as growth returns to pre-pandemic baselines but does not increase to make up for initial losses. Under this pessimistic scenario, the pandemic reduces GDP not only today but into the indefinite future.

There are also significant uncertainties about whether changes in energy demand and energy supply caused by the pandemic will be permanent. For example, transportation fuel demand decreased significantly as large shares of the workforce were forced

34 See **Comments by Environmental Defense Fund and Western Resource Advocates on the Colorado GHG Pollution Roadmap modeling effort ("Roadmap")**, May 13, 2020, at 6-7. Aspirational projections include full implementation of SB19-181.

35 These tables include only the Lepeule et al. (2012) mortality estimates when calculating the local pollution benefits.

to work from home. Alternatively, there is evidence that public transportation has decreased significantly as well due to virus concerns. Will workers stay at home permanently? Will workers commute by personal vehicle instead of public transportation and will there be an *increase* in energy demand? On the supply side, the steep decline in the price of oil has significantly changed the economics of oil production. Will prices recover and oil production, and its associated methane emissions, recover or will some wells simply never be drilled?

In the COVID-19 sensitivity scenario, we assume a pessimistic L-shaped recovery with a 3 percent drop in state GDP in 2020 and the same annual growth rate in the following years as in the baseline scenarios. However, given the large uncertainties about changes in energy demand and supply, we make no changes to underlying estimates of energy intensity, the energy demand per unit of GDP. Under this scenario, annual emissions are mostly unchanged from the CO-only scenario (and cumulative emissions are completely unchanged but banking allows annual emissions to diverge). The primary impact of the alternative COVID-19 GDP scenario is to lower expected compliance costs, both in terms of the allowance price and the policy-induced change in GDP. The GDP loss in this CO-only COVID-19 scenario is 18 percent lower than the GDP loss central case CO-only program.

4.5.4. Colorado GHG Roadmap Benchmark Revisions

In June 2020, the consultancy **Energy+Environmental Economics (E3)** presented "**CO GHG Roadmap Scenarios**" to the CO AQCC. This document included an unofficial update to the state's 2005 benchmark emissions by a) significantly revising methane emissions from natural gas and oil systems and b) updating the official non-CO_2 emissions by utilizing AR5 GHG 100–year global warming potential (GWP) estimates (as opposed to the AR4 numbers utilized in the 2015 inventory). This revision increased the 2005 benchmark emissions levels from 123 mmtCO_2e to about 139 mmtCO_2e and effectively increases the emissions targets mandated by HB1261. To test how important this revision is for our modeling results, we developed a new set of annual caps, following the same methodology as before, but using the revised 2005 and 2015 inventories.[36]

The cumulative cap for emissions between 2021 and 2030 increases from 521.1 mmtCO_2e under the targets set under the official inventory to 533.8 mmtCO_2e under the targets set under the revised inventory, resulting in a slight reduction in the stringency of the economy-wide cap-and-trade program on energy-related CO_2 emissions. Because the revision and HB1261 methane projections (which assume that methane emissions are reduced by 50 percent relative to 2005 levels) increase allowable energy-related carbon dioxide emissions, both the costs and benefits of the CO-only economy-wide cap-and-trade program are slightly less than the costs and benefits of the same program under our central case estimates using the official inventory to set the targets.

36 We also replace the methane emissions projections with the HB1261 emissions reductions provided by E3 in their publicly available **Roadmap Assumptions**.

5. Comparison to Other Policy Options

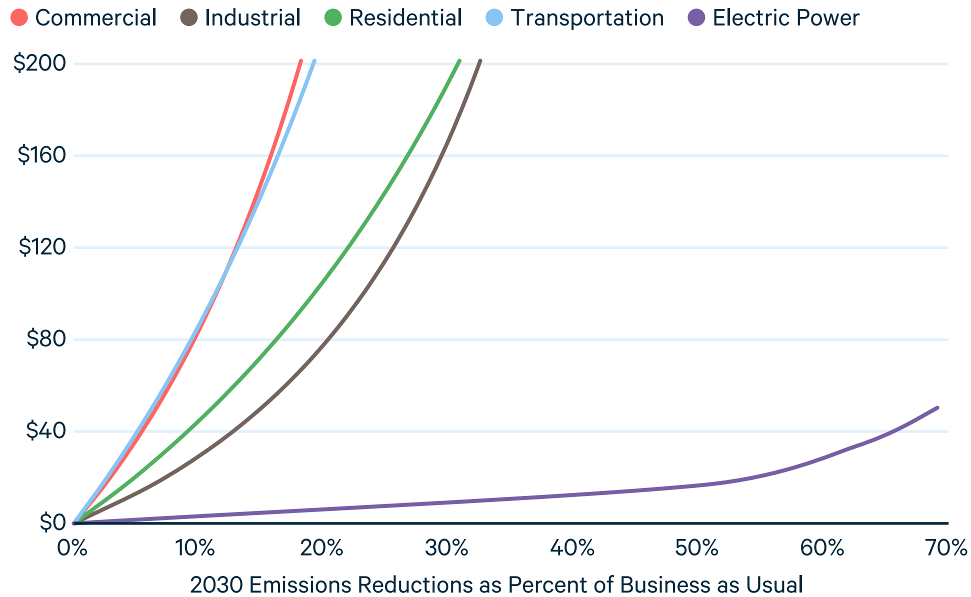
As an alternative to the economy-wide cap-and-trade program discussed above, the State of Colorado could pursue a set of sector-specific policies aimed at achieving specific decarbonization goals in each sector. For example, the state could reduce power sector emissions by requiring all coal-fired generators to retire by 2030 (and some by 2025), reduce methane emissions from natural gas and oil systems by implementing additional regulations to reduce methane leakage, reduce transportation emissions through ambitious ZEV subsidies or mandates and/or a stringent low carbon fuel standard, reduce industrial emissions through performance standards and efficiency mandates for various industrial processes, and reduce building emissions in the residential and commercial sectors by adopting strict emissions requirements for buildings, such as requiring electrification of new and existing buildings.

Colorado does not face an either/or scenario between an economy-wide cap-and-trade program and sector-specific policies. California, for example, has a wide-range of sector-specific policies including, but not limited to, a clean energy standard for the power sector, a low carbon fuel standard for transportation emissions and a mandatory solar provision on new houses in addition to their cap-and-trade program. And policies to reduce methane that are not covered under the cap-and-trade programs considered above should be pursued under all potential policy scenarios.

A sector-specific-only strategy, however, is likely to lead to significantly higher costs than could be achieved under an economy-wide cap-and-trade program because achieving deep decarbonization in certain sectors can be much costlier than in others. Sector-specific plans also don't allow for flexibility in reductions *across* sectors and cannot provide the flexibility of banking, offsets, and/or linking to other jurisdictions. As a counter-example, we modeled sector-specific cap-and-trade programs on energy-related carbon dioxide emissions for the residential, commercial, industrial, transportation, and the electric power sectors. Figure 4 shows the relationship between sector-specific caps, measured as emissions reductions in 2030 relative to BAU emissions and the estimated allowance prices from the RFF-DR model that deliver those reductions.

The cost of achieving even modest emissions reductions varies significantly across these sectors, with reductions in commercial and transportation emissions the hardest, and most costly, to realize. Alternatively, achieving emissions reductions in the power sector is projected to be much less costly than emissions reductions in other sectors. For example, the power sector reduces emissions by over 50 percent in 2030 with a carbon price of $17 (in $2020) yet at that same price the commercial and transportation sectors reduce emissions by less than 2.5 percent. At a carbon price of $200, the emissions reductions from these two inflexible sectors are less than 20 percent whereas the electric power sector is essentially decarbonized at much lower price levels. A strategy that attempted to attain the same proportional emissions reductions in each sector would therefore be exceedingly expensive and a strategy

Figure 4. Estimated Abatement Curves by Sector



Emissions units: million metric tons of CO_2equivalent (mmtCO_2e)

that attempted to attain significant but unequal percent reductions from each sector is also going to be exceedingly expensive. For example, the firm E3's "**CO GHG Roadmap Scenarios**" includes an HB1261 Targets Scenario that envisions 70 percent reductions from the power sector, 41 percent reductions from the transportation sector, 13 percent reductions from buildings (residential and commercial), and 27 percent reductions from the industrial sector, all by 2030, relative to 2015 emissions levels. According to these estimated abatement curves, an allowance price of less than $15 per metric ton on electric power sector emissions would achieve a 2030 target of 70 percent reductions relative to 2015 emissions; a separate cap on industrial emissions set to achieve a 2030 target of 27 percent reductions relative to 2015 emissions would require an allowance price above $400; for the transportation sector, a cap set to achieve a 2030 target of 41 percent reductions relative to 2015 emissions would require an allowance price above $600.[37] While not explicitly calculated, the high allowance prices for certain sectors strongly suggests that overall abatement costs are much higher than either of the cap-and-trade scenarios considered in this report.

It should also be noted that a sector-by-sector cap-and-trade program would provide flexibility to achieve emissions reductions *within* a sector in a way that mandates

37 To produce these results from the abatement cost curves in Figure 4, we need to adjust the 2030 BAU levels to 2015 benchmark levels. For example, a 27 percent reduction in industrial emissions relative to 2030 BAU requires an allowance price of about $130. But because 2030 BAU industrial emissions are greater than 2015 benchmark industrial emissions, a 27 percent reduction relative to 2015 benchmark levels actually requires a 43 percent reduction relative to 2030 BAU emissions.

and direct regulations can't. As a result, these estimates should be interpreted as a lower bound on the actual cost necessary to achieve these types of reductions with non-pricing policies in each sector. Further, an optimized approach to non-pricing approaches to each sector requires knowing *which* options are the most cost-effective today *and* ten years from now. Emissions pricing policies such as a cap-and-trade program find the least-cost reductions regardless of changes in technology costs, relative fuel costs, etc. And a cap-and-trade program places the uncertainty on the cost side of the ledger, ensuring emission reduction outcomes regardless.[38]

38 Of course, the state legislature remains the ultimate backstop and can always repeal the policy if costs get "too" high. Designing a program with an incentive structure that ensures political sustainability will be important but is beyond the scope of this report.

6. Conclusions

The state of Colorado has committed itself to an ambitious requirement to reduce its greenhouse gas emissions to 26 percent below 2005 levels by 2025 and 50 percent below 2005 levels by 2030. The state has already passed a number of policies aimed at reducing emissions throughout the next decade, including, but not limited to, the adoption of both low- and zero-emission vehicle standards and statute SB19-236, which requires utilities with more than 500,000 customers in Colorado to reduce their emissions from delivered electricity by 80 percent in 2030, relative to 2005 levels.

Despite these policies, business-as-usual projections from the CDPHE, M.J. Bradley and Associates, and the RFF-DR model all predict that the state will fall short of both the 2025 and 2030 targets and additional policies will be necessary. Cap-and-trade programs have successfully reduced emissions around the globe and we investigate the economic and environmental impacts of two illustrative cap-and-trade programs designed to meet Colorado's midterm emissions targets using the RFF-DR CGE model.

Cap-and-trade programs allow for cost-effective emissions reductions by providing flexibility *within* and *across* covered sectors. Allowing for additional flexibility for *when* and *where* reductions can occur—through the use of offsets to promote reductions outside the capped sectors, intertemporal banking of allowances that provides incentives for firms to shift their reductions over time, and program linking that allows for reductions that occur in other jurisdictions to count towards Colorado's targets—further increase the cost-effectiveness of meeting emissions targets.

Our CO-only cap-and-trade program includes offsets (in a limited amount) and allows for banking of allowances over time and achieves the state's cumulative emissions target while delivering both climate benefits and local pollution benefits to the citizens of Colorado with estimated cumulative abatement costs (undiscounted) of $6.2 billion (in $2020). The WCI-linked program, where Colorado joins California and Quebec in the Western Climate Initiative, provides additional flexibility and is more cost-effective than the CO-only approach; estimated cumulative abatement costs (undiscounted) are only $1.4 billion (in $2020) in the linked program, a reflection of the much lower allowance prices in the WRI program relative to the projected allowance prices under the CO-only program and the benefits of providing flexibility to allow for the most cost-effective reductions across participating jurisdictions.

Both policies deliver the same (undiscounted) cumulative climate-related benefits—$11.2 billion (in $2020) evaluated at the 2016 SCC using a 3 percent discount rate—but the CO-only approach delivers more reductions in local air pollutants than the WRI-linked approach—(undiscounted) cumulative benefits of reduced $PM_{2.5}$ pollution are projected to be $8.7–$19.8 billion (in $2020) under the CO-only program (depending on which mortality and morbidity estimates are applied) and $5.1–$11.6 billion ($2020) under the WRI-linked program.

An economy-wide cap-and-trade program, whether for Colorado only or linked to other states, is also likely to be much more cost-effective than sector-specific mitigation strategies. We find significant differences in the abatement costs across sectors which suggests a need for an approach that allows for different levels of emissions reductions by sector. And a cap-and-trade program automatically optimizes emissions reductions by sector both today and in the future—in response to unexpected changes in relative fuel costs, technological progress, etc.—whereas a sector-specific approach requires regulators to identify "optimal" reductions in each sector today without knowing future relative fuel costs, technological progress, etc.

The modeling exercise in this report was designed to illustrate how an economy-wide cap-and-trade program could reduce emissions, but should not be interpreted as an endorsement or recommendation for particular policy design options or cap-and-trade programs more generally. In particular, the allowance allocation scheme considered was a placeholder for more complex allocation methods. Allowance allocation remains one of the most important program design choices facing the state and its policymakers will have to balance the trade-offs created through allocating allowances to regulated entities or auctioning allowances and the trade-offs created by how those allowance values are used to mitigate impacts on energy-intensive trade-exposed and/or low to moderate income households if the state were to pursue a cap-and-trade approach to meeting its emissions targets.

Finally, our report focused on meeting the 2025 and 2030 emissions targets without a focus on meeting the longer run 2050 target. A cap-and-trade program on emissions through 2030, combined with complementary policies that promote and accelerate the energy transformation through changes in infrastructure, directed technical change, and investment throughout the state, can put the state into a much stronger position to achieve its deep midcentury decarbonization goals.

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Appendix A. Model Description

The RFF-DR CGE model shares many features with the Goulder-Hafstead Energy-Environment-Economy (E3) model.[39] Each regional economy is modeled as a collection of forward-looking agents: firms representing distinct industries within that region, a single representative household for that region, and regional and federal governments. The model captures the interactions among agents both within and across regions and solves for market-clearing prices in each period. Each agent has perfect foresight, and the model is solved in each period until it converges to a new steady-state balanced-growth equilibrium. The model is benchmarked to 2015 and each period represents two-years; even year projections are interpolated from the odd year projections. For the purposes of this analysis, we focus on results through the year 2030.

Two features of the Goulder-Hafstead E3 and RFF-DR CGE models distinguish them from other national or regional dynamic environment-related CGE models. These features make them especially well-suited for analysis of carbon pricing policies at the national or state level. First, the models combine relatively detailed treatment of energy supply and demand with a detailed treatment of the tax system. This detailed treatment allows the model to evaluate the critical interactions between climate policy and state and federal taxes and spending. These interactions play a fundamental role in determining the economic costs of climate policy.

Second, the models include the adjustment costs associated with the installation or removal of physical capital at the region-industry level. These costs affect the pace of capital reallocation across industries within and across regions and ultimately affect the speed at which each regional economy responds to a new national or regional climate policy. In addition, the adjustment costs are necessary to model the differential impacts of environmental policy on profits and asset values across industries and regions.

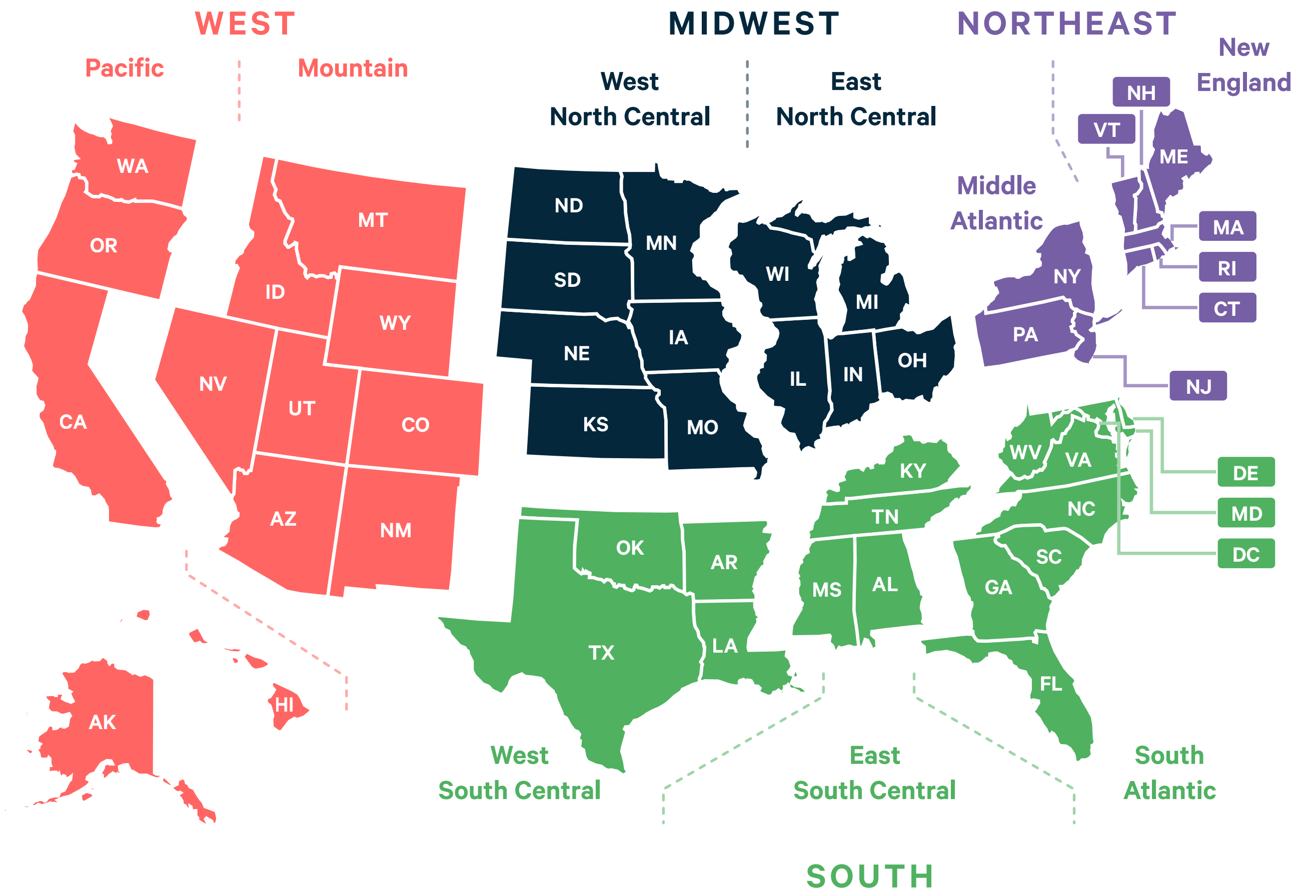
For this analysis, the RFF-DR CGE model breaks the United States into three regions: Colorado, the rest of the West Census region, and a single region representing the Midwest, South, and Northeast Census regions. Figure A.1 displays census regions and divisions. The number of regions is limited to aid in model solution time.

Regional social accounting matrices (SAMs) from the IMPLAN Group provide information on market flows and nonmarket financial flows among firms, consumers, and the government (IMPLAN 2017).[40] For this analysis, industrial sectors are aggregated into 15 industries that produce distinct commodities. Table A.1 displays the unique industries and commodities in the RFF-DR CGE model. The IMPLAN data

39 For a complete description of the E3 model, see Goulder and Hafstead (2017).

40 The RFF-DR CGE model uses 51 state (including District of Columbia) SAMs from IMPLAN and aggregates them to the specified regional aggregation.

Figure A.1. Census Regions and Divisions



Source: Energy Information Administration

are augmented with information on production, physical consumption, and total expenditures by energy good from the US Energy Information Administration's State Energy Data System (EIA 2018a, EIA 2018b, EIA 2018c). The regional SAMs include data on total exports and imports to other regions within the United States for each commodity but do not include information on state-to-state or region-to-region trade flows. To capture these flows in the economic modeling, we estimate a trade matrix to be consistent with domestic exports and imports of each commodity. Fixed emissions coefficients for carbon dioxide are calculated using EIA data on emissions by state by sector (EIA 2018d) and fixed emissions coefficients for criteria air pollutants are calculated from EPA data on pollutant emissions by major source (EPA 2018b). Finally, we use Bureau of Economic Analysis data to convert personal consumption expenditures by commodity into consumption spending on 10 distinct consumer goods (BEA 2018). All data are from 2015.

Table A.1. Industry and Consumer Goods in the RFF-DR CGE Model

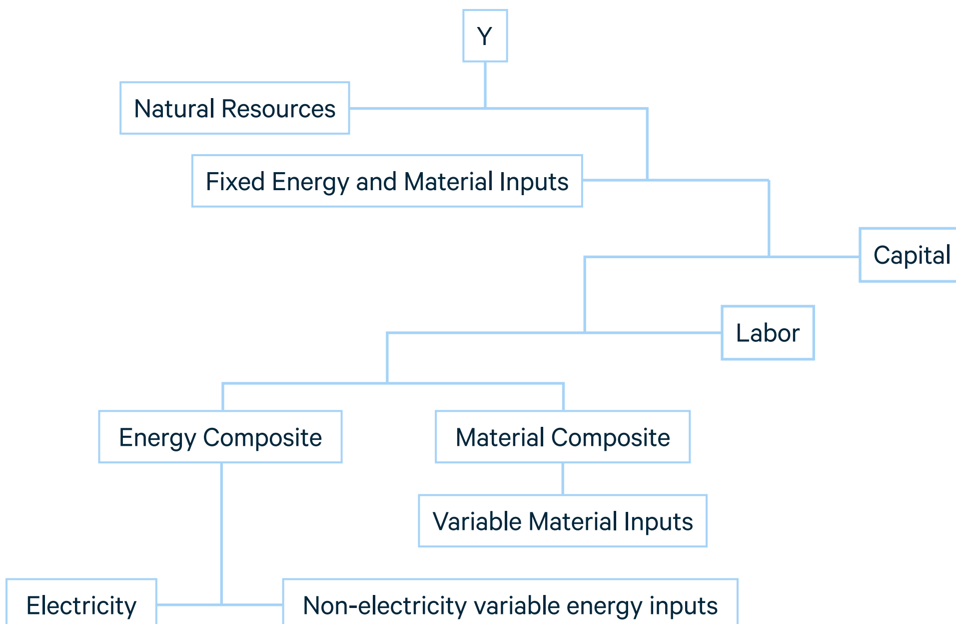
Industry	Consumption Goods
Oil Extraction	Motor Vehicle: New and Used
Gas Extraction	Motor Vehicle: Services
Coal Mining	Motor Vehicle: Fuels
Electricity Generation: Fossil	Motor Vehicle: Electricity
Electricity Generation: Nuclear, Hydro, Other	Non-Personal Transportation
Electricity Generation: Solar and Wind	Housing
Electric Transmission and Distribution	Electricity (non-vehicle)
Natural Gas Distribution	Natural Gas
Petroleum Refining	Fuel Oil and Other Fuels
Industrial Sector (Non MV Manufacturing)	Other Goods and Services
Motor Vehicle Manufacturing	
Wholesale and Retail Trade	
Transportation	
Commercial (Finance, Communication, Services)	
Real Estate and Owner-Occupied Housing	

A.1. Production

Output from each industry stems from a nested structure of constant-elasticity-of-substitution (CES) production functions. Figure A.2 displays this structure. Variable intermediate inputs of energy (oil extraction, gas extraction, coal mining, electricity generation, electricity transmission and distribution, natural gas distribution, and petroleum refining) and of materials (industrial sector, motor vehicle manufacturing, trade, transportation, commercial sector, and real estate and owner-occupied housing) are aggregated into an energy composite, E, and a materials composite, M. At the next level of the nest, the variable energy and material composites are aggregated into an intermediate input composite using function h. At the next level, the intermediate input composite $H = h(E,M)$ is aggregated with labor using function g, $G = g(L,H)$ and at the next level the variable input composite is combined with capital using function x, $X = x(K,G)$. For each of these CES nests, elasticities of substitution for each industry are taken from common estimates from the economic literature. For each industry, specific intermediate inputs are considered fixed proportion inputs: the input must be in proportion to output (for example, crude oil input into petroleum refining). A fixed Leontief function f combines these inputs, F_E and F_M, with the other inputs, $F = f(F_E,F_M,X)$. For extraction industries (oil, gas, coal) and Electricity Generation: Nuclear, Hydro, Other, natural resources are required to produce outputs. For these industries, inputs are combined with natural resources via a CES production function, $Y = y(R,F)$. For extraction industries, the elasticity of substitution is calibrated to match fuel supply elasticities calculated by comparing production across EIA's AEO alternative reference case scenarios (0.15 for oil, 0.2 for gas, 3.8 for coal) and the Electricity Generation: Nuclear, Hydro, Other elasticity is calibrated such that the fuel price elasticity is approximately zero to limit significant increases in these types of generation in response to policy. For industries without natural resources, output is simply $Y = F$.

Capital adjustment costs are modeled as the sacrifice of output associated with the process of investing in capital. Specifically, net output is equal to gross output minus adjustment costs, $\phi(I/K)\times I$, represents the adjustment costs (in terms of lost output). Adjustment costs have the same functional form as Goulder and Hafstead (2017).

Figure A.2. Nested Production Function

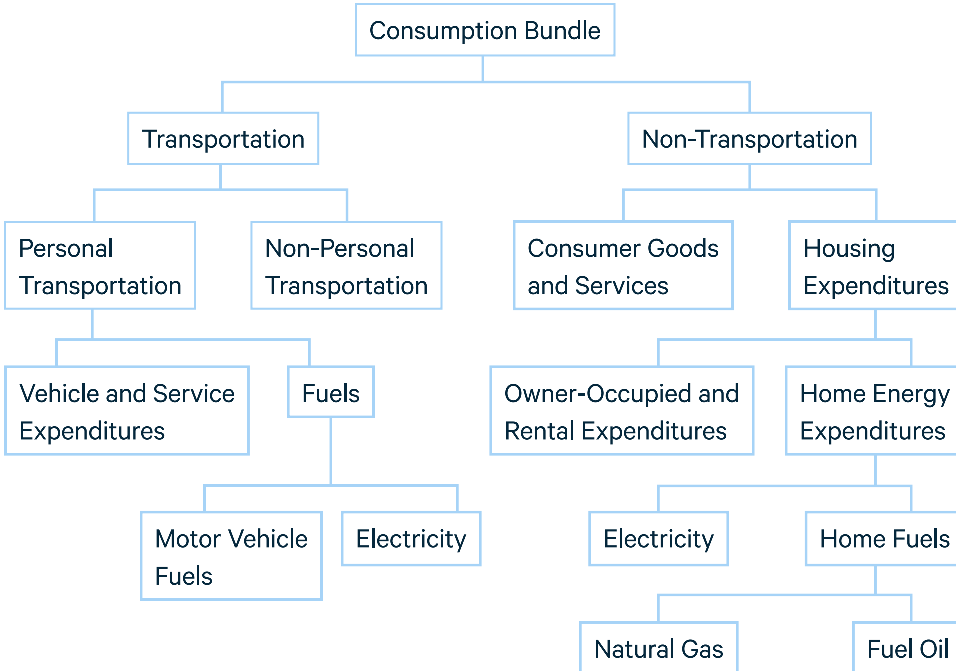


A.2. Consumer Behavior

RFF-DR modeling of consumer behavior captures several key aspects of consumer choice: the choice between work hours and leisure time, the choice between current consumption and saving for future consumption, and the allocation of current consumption expenditure across various consumer goods and services. There is a single, representative household for each region.

RFF-DR modeling of household consumption follows Goulder and Hafstead (2017) with the exception of the aggregation of consumer goods and services into a consumption bundle. Goulder and Hafstead (2017) used a Cobb-Douglas aggregation of goods and the RFF-DR uses a nested utility structure as specified in Figure A.3. Elasticities of substitution are common values taken from the literature.

Figure A.3. Consumption Bundle Nest



A.3. Government

There is a federal government and state/local governments in each region. The governments collect taxes to finance expenditures on goods, services, and labor used to produce a government service. The production function is Leontief and the level of government services provided remain fixed over time. Adjustment to lump-sum taxes are used to balance the government budget constraint as is standard in the CGE literature.

A.4. Regional Trade

Each good purchased by households, producers, or the government in a particular region is an aggregate of goods produced in the foreign sector, the own region, and other regions. Inter-regional trade is modeled as a national market: each region sells goods to the national market (domestic exports) and buys back goods from the national market (domestic imports). There are CES elasticity of substitution parameters determining the substitutability of domestic and foreign goods and own-region and national market goods. All fossil fuels are sold exclusively on a national market. There are Western-region and Eastern-region electricity markets to reflect the lack of trade across interconnect regions in the United States.

Appendix B. Supplementary Tables

Table B.1. Annual Net GHG Targets and Energy-Related CO_2 Cap

Year	Net GHG Targets	Energy-Related CO_2 Emissions Cap
2021	103.2	69.4
2022	100.3	66.5
2023	97.4	63.5
2024	94.5	60.6
2025	91.6	57.5
2026	85.7	51.7
2027	79.7	46.1
2028	73.8	40.7
2029	67.9	35.3
2030	61.9	29.7
Cumulative	855.9	521.1

* mmtCO_2e

Table B.2. Annual Costs and Benefits of Alternative Cap-and-Trade Programs

CO-Only Program

Year	Change in GDP relative to BAU	Climate-Related Benefits	Local Health Benefits (Krewski et al.)	Local Health Benefits (Lepeule et al.)
2021	-$1,062	$1,019	$949	$2,162
2022	-$1,172	$1,037	$924	$2,104
2023	-$1,283	$1,055	$898	$2,046
2024	-$1,380	$1,062	$867	$1,976
2025	-$1,477	$1,069	$836	$1,905
2026	-$1,655	$1,112	$835	$1,902
2027	-$1,834	$1,156	$834	$1,899
2028	-$2,014	$1,193	$838	$1,908
2029	-$2,194	$1,230	$842	$1,918
2030	-$2,380	$1,283	$849	$1,932
Cumulative	-$16,451	$11,216	$8,672	$19,752

WCI-Linked Program

Year	Change in GDP relative to BAU	Climate-Related Benefits	Local Health Benefits (Krewski et al.)	Local Health Benefits (Lepeule et al.)
2021	-$592	$1,019	$558	$1,273
2022	-$653	$1,037	$544	$1,240
2023	-$714	$1,055	$530	$1,208
2024	-$758	$1,062	$507	$1,156
2025	-$801	$1,069	$484	$1,103
2026	-$889	$1,112	$484	$1,103
2027	-$977	$1,156	$484	$1,102
2028	-$1,068	$1,193	$488	$1,112
2029	-$1,161	$1,230	$492	$1,122
2030	-$1,255	$1,283	$499	$1,138
Cumulative	-$8,866	$11,216	$5,070	$11,557

* Millions $2020

Table B.3. Reference Case Criteria Air Pollutants and Projected Level Changes under Alternative Cap-and-Trade Programs

	Historical Inventory	BAU Projections		CO-Only Program		WCI-Linked Program	
	1000 metric tons			Reductions Relative to BAU 1000 metric tons			
Criteria Air Pollutant	**2017**	**2025**	**2030**	**2025**	**2030**	**2025**	**2030**
Carbon Monoxide	711.6	607.6	566.7	66.16	72.30	26.53	30.80
Nitrogen Oxide	172.4	131.1	119.9	22.92	22.99	13.15	13.46
PM_{10}	22.2	20.7	20.2	1.10	1.25	0.45	0.54
$PM_{2.5}$	14.2	13.2	12.9	0.79	0.89	0.33	0.39
Sulfur Dioxide	19.2	9.2	8.2	5.58	4.85	4.73	4.35
Volatile Organic Compounds	202.3	182.7	165.5	11.95	13.07	4.73	5.44
Ammonia	3.7	2.9	2.6	0.22	0.24	0.08	0.10

Note: Includes only criteria air pollutants from fuel combustion (stationary and mobile) and industrial processes.