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ABSTRACT

Renewable portfolio standards (RPS) have been implemented in many US states as a mechanism to reduce greenhouse gas (GHG) emissions and become more energy independent. One of these states, Colorado, has enacted an RPS requiring 20% of electricity sold within the state come from renewable sources by 2020. In this paper we present results of a dynamic computable general equilibrium model of the state economy to demonstrate the economic impacts of the RPS. Results are presented for the RPS alone and in conjunction with the state's long-term emissions reduction goals. We find that compared to the emissions reduction alone, leakage rates and emissions allowance prices are reduced in early years, but this benefit is lost as the emissions limit becomes more restrictive.

1. Introduction

Across the US, state legislatures are rapidly enacting renewable portfolio standard (RPS) legislation. These policies are popular because of their perceived benefits of reducing greenhouse gas emissions associated with climate change, increasing energy independence, and promoting investments in cleaner energy production. RPS policies mandate that a specified percentage of electricity sold or generated in a region must be generated by renewable means. Subsidies and other incentives may be used alongside an RPS to meet the goal. Allowable sources may vary, and some technologies may be favored by the legislation.

In this paper we use a dynamic computable general equilibrium (CGE) model to investigate the impacts of such a policy on the Colorado economy. We measure the economic impacts of the policy, and then consider the interactions between the existing RPS requirements and a proposed reduction in total carbon dioxide (CO_2) emissions. The RPS is shown to reduce emissions leakage and allowance prices when the emissions reduction is small, but is not binding under the strictest restrictions proposed. We present estimates of the emissions leakage under these policy cases, and find that the RPS does not reduce emissions leakage when it is not binding.

The next section describes RPS policies in more detail, and provides information on Colorado's renewable energy policies. The third section details the modeling of the renewable electricity generation sector. Section 4 presents outcomes for the Colorado economy under the RPS with and without a permit scheme used to meet the state's long term emissions reduction goals. The final section offers conclusions about the costs and benefits of using an RPS as part of a CO_2 emissions reduction within the state.

2. Characteristics of renewable portfolio standards

Renewable portfolio standards are favored at the moment because of a few key perceptions. Lyon and Yin (2010) identify several factors that influence the enaction of an RPS in a region, including overall air quality, level of unemployment, concern for the environment, dominant political party, and prominence of the renewable industry. RPS policies are seen as beneficial to the economy and the environment, and as a way to stabilize energy supply and prices in the future (Rabe (2006)). As a result, RPS policies are able to attract a broad coalition of support, with the economic benefits often outweighing environmental concerns for lawmakers.

Restrictions on electricity generation that raise production costs may encourage generators to relocate from the regulated area. The associated loss of employment and/or tax revenue makes such measures politically difficult. However, an RPS policy regulates electricity sold in an area regardless of its origin, thus reducing the incentives for generation to shift to other areas. Additional in-state requirements or incentives are often used in an effort to expand the renewable industry, which is perceived as creating more jobs than traditional electricity generation (Lyon and Yin (2010)). For instance, Colorado allows generators to count more than one KWh for some KWh of renewables produced within the state.

For a small jurisdiction, an RPS may be more effective at reducing emissions than other policies. The ability of Colorado residents to import renewable electricity from out of state is limited by the existing capacity and demand from other states. Current capacity limits require that more renewable capacity be installed to meet the RPS regulation. In addition, RPS policies can also help to reduce local air pollutants produced by electricity generation.

Emissions leakage occurs when polluting activities move to other jurisdictions with less stringent regulation. Emissions reduction policies increase production costs in the affected jurisdiction relative to outside areas. The productive activity, and the associated emissions, relocate from the regulated area, while consumers within the area can import the final goods. The global level of emissions may not be significantly reduced under such a policy. While the relocation of economic activity may protect sensitive areas from local pollutants, it is not as helpful in the case of a global pollutant like CO_2. Emissions leakage under the RPS should be small, because electricity sold in the state is regulated regardless of where it was generated. Retailers cannot import dirtier electricity from across state lines in order to meet the standard for a smaller number of instate facilities.

An RPS does not mandate that any one specific technology be used to reduce emissions. The flexibility to choose from a range of alternative energy sources exists, allowing generators to invest in the cheapest, most efficient sources for their particular operation. Colorado's policy includes the ability for generators to buy renewable credits from other generators who exceed their requirements, including small generators that are not covered at all or face lighter regulation under the law. This flexibility should reduce the costliness of lowering emissions through other means, such as technology requirements. Palmer and Burtraw (2005) find that RPS policies are less costly than tax credits at reducing emissions, and less costly than both tax credits and cap-and-trade systems at fostering the introduction of renewables.

While a standard may be a useful tool for reducing emissions in small jurisdictions, there are some drawbacks to such a policy. Most importantly, the RPS only focuses on electricity generation, when opportunities for emissions reduction exist throughout the economy. An RPS does not require a specific technology, but mandates an increase in more expensive forms of generation. In most cases, emissions abatement, such as fuel switching or direct carbon sequestration at the stack, is not counted towards the standard, even though this technology may be cheaper at reducing emissions. Measures that improve energy efficiency are also not usually counted toward meeting an RPS (with exceptions). By restricting the means of achieving emissions reductions, these reductions may not be made in the least-cost manner. Furthermore, the exact emissions reduction achieved is not known, and depends on the specific technologies used in electricity generation, electricity demand, economic growth, and other factors.

2.1. Interactions with other policies

In many cases, RPS policies are one tool used to meet a larger emissions reduction goal. Such is the case for the Regional Greenhouse Gas Initiative (RGGI) in the US Northeast (Regional Greenhouse Gas Initiative (2007)), which is using an RPS to reduce emissions leakage resulting from its tradable emissions permit scheme.

Tradable emissions permits (or allowances), originally proposed by Crocker (1966) and Dales (1968), have been successfully used to reduce or eliminate many pollutants in the US and other nations. The European Union is currently using emissions permits to limit output of GHGs, and such policies have been used nationally and sub-nationally within the US to reduce emissions of other pollutants. As pointed out by Hanley et al. (1997), a negative externality, such as air pollution, occurs when there is a lack of property rights for environmental resources. A tradable permit system establishes these property rights and a market price for the right to pollute. Montgomery (1972) shows that a competitive market for permits results in a price that minimizes the cost of emissions reduction.

The Marginal Abatement Cost (MAC) curve gives the cost to firms of avoiding pollution. This cost rises with each unit of emissions reduction undertaken. A firm's abatement activities may include reducing output of goods and services, using less polluting production processes, or using technology to collect pollutants before they are released into the atmosphere (Hanley et al. (1997)). Each firm chooses to minimize their abatement costs, subject to regulation. In the case of a permit policy, a firm's MAC curve represents its demand for permits, and the horizontal sum across all firms gives the market demand for permits. The regulator chooses the acceptable level of emissions, and the market determines a price of permits.

Alternatives to tradable permits include emissions taxes or command-and-control policies, which require a particular technology be adopted or set maximum emissions per source. In contrast with tradable permits, to achieve the same level of emissions through a tax, the regulator must estimate the MAC curve and choose a tax rate that intersects MAC at the desired level of emissions. Estimating the MAC may require that the regulator gather large amounts of information on the costs of pollution abatement (Tietenberg (2006)). This process can be expensive, and the regulation may be inefficient if a tax, penalty, or emissions cap is set at the wrong level. Monitoring emissions and enforcing penalties add to the costs of these traditional policies.

The interaction of RPS and permit policies may have positive and negative effects. These effects are investigated by Stavins (1998), who asks the question of how the pre-existing regulatory environment can affect the operation of a permit scheme, and by Bushnell et al. (2008), who state that the flexibility that is the key advantage of market-based mechanisms" is reduced when combined with other regulation. This interaction is particularly relevant for the highly regulated electricity industry (Goulder et al. (1999)). Adding an RPS to a permit scheme may raise the cost of achieving a desired reduction in emissions, due to the additional constraints on the manner in which emissions are reduced. Without the RPS emissions are reduced where it is least expensive to do so. However, with an RPS, some of the emissions reduction is undertaken through the installation of renewable electricity generation technology, which may be more expensive than other abatement methods, such as reducing output, switching fuel inputs, or retrofitting emissions scrubbers.

On the other hand, efficiency standards may offset some of the negative side-effects from permit schemes, such as emissions leakage. When emissions permits are used alone, increased production costs push industries out of the regulated area, and residents import final goods. Using an RPS with a permit policy may prevent this relocation because the good must be produced in a particular manner, regardless of its origin. Not only does this act to reduce leakage, it also reduces the loss of employment caused by the policy. In fact RPS policies are often enacted in hopes of drawing new investment and employment in renewable technology to the area. Reducing the demand for carbon-based fuels in the electricity sector may also reduce the price of permits.

2.2. Colorado's RPS policy

The state of Colorado is particularly sensitive to the effects of climate change, with the American West currently warming faster than the global average (Saunders et al. (2008)). Residents of Colorado rely on a mountain snowpack for water supplies throughout the year. Current forecasts indicate that less snowfall and warmer winters can be expected, leading to drought conditions and increasing the number and intensity of wildfires. Winter sports seasons may be shortened, wildlife habitat may be reduced as animals move to higher elevations, and forests may be more prone to insect damage (Moscou (2008), Kurz et al. (2008)). These impacts would lead to reductions in the tourism and sporting activities for which the state is famed, as well as agricultural activities important to the state's identity. Sensitivity to water concerns, enjoyment of outdoor activities, and a respect for wildlife have motivated Colorado residents to request action on this issue.

One highly publicized threat to Colorado is the mountain pine beetle. With warmer winters, fewer of these insects are killed by severe freezing temperatures, and the insects can move to higher altitudes, compounding the risk for wildfires. The mountain pine beetle affects several types of pine found in Colorado forests and are controlled by freezing temperatures (Leatherman et al. (2007)). The affected area is quite large, and some camping and wilderness areas have been closed because of fire danger.

Seventy percent of state's population of lodgepole pines have been killed and the rest are threatened (Moscou (2008)).The loss of these trees is not merely aesthetic; the potential for fire caused by these dead pines endangers property and public safety. The burning or rotting of these logs will release more carbon emissions. Kurz et al. (2008) suggest that recent beetle outbreaks in British Columbia, Canada have turned that region from a "small net carbon sink to a large net carbon source."

In 2007, the state of Colorado became the first in the US to pass an RPS by voter initiative (Rabe (2006)). Amendment 37 originally required 10% of electricity be generated by renewable sources by 2010. The legislature then increased this requirement to 20% from renewables by 2020. The renewable sources allowed by this amendment include wind, solar, geothermal, biomass, hydroelectric, and hydrogen fuel cells; nuclear power is absent.[1] Table 1 displays the January 2013 electricity generation profile for Colorado.[2] Hydroelectric makes up 4% of generation, with another 14% generated from other renewable sources, mostly wind and solar (United States Energy Information Agency (2009)).

The motivation provided for this amendment declares that Colorado's renewable resources are underutilized, and that by developing these resources, growing energy demand can be met at a lower cost. At the same time, the regulation will help to improve environmental quality and reduce the electricity sector's demand for scarce water resources (used in cooling traditional power plants). Finally, the measure is hoped to bring jobs to the state in the renewable technology industry and grow the economies of rural areas where these facilities can be cited. The state predicts that this measure will add $1.9 billion to the state GDP between 2008 and 2020.

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[1] The full text of this amendment is available at http://www.dsireusa.org/documents/Incentives/CO26R.htm

[2] Note that this mix will change throughout the year as demand changes.

Energy Source	% of CO generation	% of national generation
Petroleum Fired	0%	0%
Coal Fired	66%	2.2%
Natural Gas Fired	17%	0.6%
Hydroelectric	4%	0.1%
Other Renewables	14%	0.5%
Total Renewables	18%	
Total MWh	4,787	3.4%

Table 1: January 2013 electricity production in Colorado. Source: United States Energy Information Agency (2013).

The amendment that sets the RPS includes other restrictions on its implementation. Utility customers are entitled to a $2.00 per megawatt rebate for solar generation. The price increase that utilities can pass on to residential consumers is limited to 50 cents per month per household. Utilities cannot claim eminent domain over land to cite facilities. Finally, tradable renewable credits are established, allowing small, uncovered facilities to sell their renewable capacity to larger companies.

House bill 1281,[3] enacted March 27, 2007, increased the percentage of renewables required by the RPS to 20% by 2020. Of the renewables required in each year, four percent must come from solar, and half of this amount should come from household solar units. Shortfalls may be met though renewable energy credits or efficiency and conservation projects. Cooperatives, which were not covered by the original legislation, are included in this bill, and they are required to meet a goal of 10% renewable generation by 2020.

The bill includes additional incentives for new facilities to be cited within Colorado, in an effort to meet the goals of stimulating both employment and rural economic activity. Large generators may count 1.25 KW for each KW of renewable production within Colorado, co-ops may count 1.5 KW for each KW produced in state, and each KW of solar may be counted as 3

[3] Colorado House Bill 07-1281, Concerning increased renewable energy standards. Available at http://www.leg.state.co.us/Clics/Clics2007A/csl.nsf/fsbillcont3/C9B0B62160D242CA87257251007C4F7A?Open&file=1281 enr.pdf.

KW until 2015. While this lessens the amount of renewable generation required under the legislation, it reduces the incentive to import renewable electricity from out of state.

In 2008, Governor Bill Ritter announced goals for the state to reduce its CO_2 emissions by 20 percent by 2020, and by 80 percent by 2050, from 2005 levels (Ritter (2007)). Currently, these goals are not binding, but these, or similar reductions, may be pursued in the future.
In addition, several other initiatives are in place to promote renewable energy use within the state. The Colorado Climate Fund allows individuals and businesses to purchase carbon offsets at $20 per ton.[4] Proceeds of the fund are to be used for in-state projects in the areas of anaerobic digestion, solar water heater installation, biogas, energy efficiency, and transportation. The Governor's Energy Office provides high efficiency light bulbs, appliances, and insulation to low-income families. The office has also set goals for water use, paper use, and waste reductions for state offices.[5] Rebates are available for the installation and maintenance of solar cells. Programs are in place to support the development of small hydroelectric and wind facilities, biomass, and biogas projects. Heating facilities using woody biomass are also being installed. This fuel includes wood chips from the routine thinning of forests as well as trees killed by pine beetle infestation.

[4] Please see http://www.coloradocarbonfund.org/ for more information.

[5] Please see http://www.colorado.gov/energy/ for more information on the various programs.

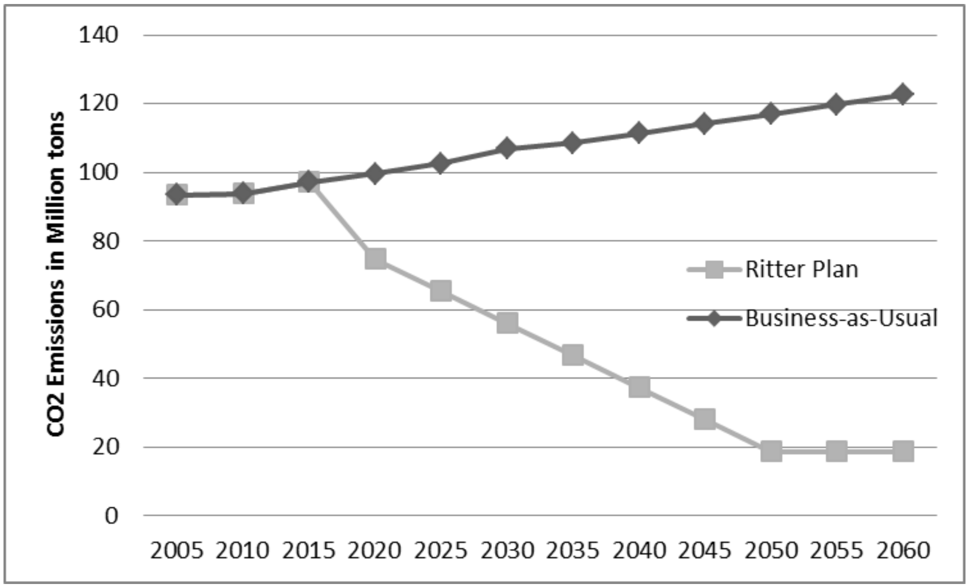


Figure 1: Carbon Emissions under Business-as-usual (BAU) and emissions reduction scenarios. The suggested 80% reduction of emissions from 2005 levels in 2050 corresponds to an 85% reduction from BAU levels by 2060. Source: United States Energy Information Agency (2008c).

The ability of states to meet their RPS requirements through imports is limited by the demand for renewables from other states with similar policies. Currently, 31 US states have some sort of clean electricity goal. These goals range from Iowa's 105 megawatts from renewable sources, which has been in effect since 1983, to California's 20% renewable power by 2010. Ohio requires a 25% \alternative" energy standard by 2025, with at least 12.5% from renewables, and the rest to include third-generation nuclear plants, fuel cell production, clean coal technologies, and increased efficiency in generation. Minnesota's goal is a 25% overall share of renewables by 2025, with XCel energy, which provides over 50% of the state's electricity, meeting a restriction of 30% by 2020. In addition to Colorado, five other states (Delaware, Maryland, Nevada, New Jersey, Pennsylvania) require a set level of the renewable standard be met by solar production (Pew Center for Global Climate Change (2009)).

3. Model

3.1. Computable general equilibrium model of Colorado

The economic impacts of the Colorado's proposed policies are estimated by a computable general equilibrium (CGE) model of the state. This model generates a baseline forecast of the Colorado economy, calibrated to 2005 IMPLAN data and forecasts of emissions, energy production, and energy prices from the US Energy Information Agency (United States Energy Information Agency (2008b), United States Census Bureau (2005), United States Energy Information Agency (2008c), United States Energy Information Agency (2008a)). The dynamic model assumes forward-looking agent behavior and links investment to capital accumulation (Rutherford (1998), Rutherford (1995)). An infinite-horizon approximation is made over the finite model period according to Lau et al. (2002). Nested CES production functions focus on energy substitution for production of goods and consumer welfare. This baseline forecast can be compared to a Ritter Plan scenario in which tradable permits are introduced to meet the state's emission reduction goals.

The model runs from 2005, the year from which emissions reductions are based, to 2060, ten years beyond reaching the final emissions reduction goal. The model is solved in five year increments; by reducing the number of solution years, a greater level of detail is possible in each solution. Nine sectors and one representative household are modeled, with an emphasis on the production of energy. The five energy sectors include crude oil and gas production (CRU), coal mining (COL), refined oil products (OIL), natural gas (GAS), and electricity generation (ELE). The non-energy sectors are agriculture (AGR), manufacturing (MAN), services (SRV), and an aggregate of other small, energy-intensive sectors such as mining and transportation (OTH). Leakage rates are computed for each of these sectors in each model year.

3.2. Renewable Technology

Under House Bill 1281, electricity used in Colorado must be composed of 10% from renewables by 2010, 15% by 2015, and 20% from 2020 on. In 2009, an annual average of 9% of electricity was generated by renewable sources. As of 2012, both of the state’s two investor-owned utilities have reported that they have complied with the standard through 2011. Xcel

Energy reported in 2012 that they are expecting to meet requirements ahead of schedule (Xcel (2012), DSIRE (2013)). In cases where the RPS is not considered, renewable production is assumed to remain constant at the 2009 level. Adding the RPS policy requires that the fraction of renewables be adjusted. This adjustment is made in the renewable electricity sector in the CGE model.

Within the model of the Colorado state economy, electricity can be generated by conventional or renewable technology. The renewable sector uses no fuel inputs, but requires an additional amount of capital. Inputs are used in fixed proportions, to prevent substitution away from this capital, which is specific to the renewable sector. The household is initially endowed with a level of renewable capital chosen to meet the observed level of renewable generation. This amount is determined by a constraint that requires the specified fraction of electricity use, or imports plus production, that must be exceeded by the renewable sector. An assumption is made that the same 9% of production comes from renewables in the generation of imported and domestic electricity in the baseline. Capital for renewable generation, above the benchmark level, comes at an increasing cost, relative to generic capital. We assume a constant elasticity of supply, so renewable penetration comes at ever-increasing costs. In the central case we assume an elasticity of supply of two.

Given the current state of renewable technology, it is reasonable to assume that in the near future, more expensive technologies will be needed to meet the RPS requirements. The share of renewables must increase over the next five to ten years, and considering the time needed to design and receive approval for new installations, many of the required projects are already well underway. Over time, however, technological progress may drive down the cost of renewable technology. In fact, a major argument for RPS policies is that they will encourage innovation in renewable electricity generation. Rather than modeling this behavior explicitly, we capture this innovation implicitly by including the EIA forecasted prices and quantities of energy commodities. These forecasts include current and pending renewable policies across the country, energy efficiency gains, and technological improvement (United States Energy Information Agency Office of Integrated Analysis and Forecasting (2009)).

The constraint that governs the level of renewable electricity production ensures that the RPS must be met or exceeded. This allows for the growth of the renewable sector in the business as usual scenario, which is consistent with the forecasted increases in prices of energy commodities. Also, in the case of both the permit policy and the RPS, we expect that the RPS may not be binding as traditional electricity production declines. Not only are investments made in renewable energy technologies, but as traditional generation declines, the fraction of electricity produced through renewable means increases.

3.3 Leakage rate

In order to understand the true emissions reduction associated with a policy, a leakage rate can be used. This rate is defined as the tons of new emissions generated outside of the regulated area per ton of emissions reduction achieved within the area. Formally, the leakage rate for a sector *i* in time *t* is defined as:

$$\text{Leakage rate}_{it} = \frac{\text{emissions content of new imports}}{\text{emissions reduction}} = \frac{(M_{it}^{S} - M_{it}^{B} + X_{it}^{S})(\frac{E_{it}^{B}}{Y_{it}^{B}})}{E_{it}^{B} - E_{it}^{S}}, \qquad (1)$$

where

E^{B}_{it} = Benchmark emissions for sector i in period t,

E^{S}_{it} = Scenario emissions for sector i in period t,

M^{B}_{it} = Benchmark imports of good i in period t,

M^{S}_{it} = Scenario imports of good i in period t,

X^{B}_{it} = Benchmark exports of good i in period t,

X^{S}_{it} = Scenario exports of good i in period t,

Y^{B}_{it} = Benchmark production of good i in period t,

H^{B}_{it} = Benchmark household emissions in period t, and

H^{S}_{it} = Scenario household emissions in period *t*.

The leakage rate for sector *i* in period *t* equals the increase in imports of good *i* under the policy compared with the business-as-usual level, plus the reduction in exports, times the carbon content of the good, divided by the reduction in emissions for sector *i* within the state.

Put another way, it is the tons of emissions exported to other areas for each ton of emissions reduction achieved by the policy. To get an overall leakage rate for the state in year *t*, the sectors are summed in the following manner:

$$\text{Overall leakage} = \frac{\sum_{i=1}^{9}\left[\left(M_{it}^{S}-M_{it}^{B}+X_{it}^{B}-X_{it}^{S}\right)\left(\frac{E_{it}^{B}}{Y_{it}^{B}}\right)\right]}{\sum_{i=1}^{9}\left(E_{it}^{B}-E_{it}^{S}\right)+\left(H_{t}^{B}-H_{t}^{S}\right)}. \quad (2)$$

The reduction in emissions generated by households is included in the overall leakage rate so that all emissions reductions are accounted for. Household generation of emissions cannot be exported because we do not consider policy-induced migration. In practice, leakage can be difficult to measure, as generation technology differs between states and individual utilities. Farnsworth et al. (2007) offers suggestions on measuring emissions leakage in the RGGI, while Alvarado (2006) proposes a methodology for California.

4. Results

As discussed above, we consider a reduction in Colorado's CO_2 emissions by 20% from 2005 levels by 2020, and 80% by 2050, based on the governor's recommendations. In the CGE model, agents are endowed with a sufficient quantity of permits to result in a zero-price of permits until the reduction is undertaken. In 2020, the quantity of permits is reduced by 20% of their 2005 level to force an equivalent reduction in emissions. CO_2 emissions are directly linked to fuel inputs, allowing for the possibility of a system that attaches emissions permits to fuels, instead of monitoring the emissions themselves. In the model, every five years the number of permits is reduced by 10%, resulting in a 2050 level that is 80% below the 2005 emissions output. After 2050, the allowable emissions are held constant. These reduction assumptions are displayed in Table 2. We consider four scenarios: a baseline case including EIA projections of energy use, energy prices, and CO_2 emissions; a case in which Colorado's stated goals for emissions reduction are met through the use of tradable emissions permits; a case describing the RPS policy; and a case in which both the RPS and tradable permits are used to reduce emissions.

Year	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060
Percent reduction from 2005 levels	-	-	20%	30%	40%	50%	60%	70%	80%	80%	80%

Table 2: Percent reduction from 2005 emissions levels required in each year in the tradable emissions permit scenarios.

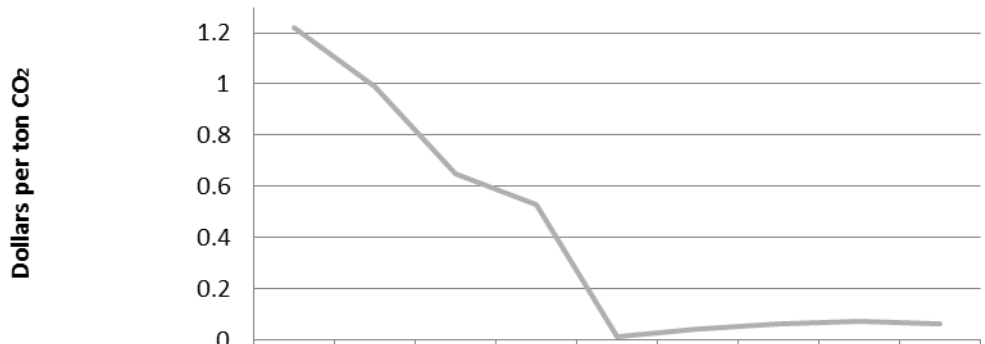
The RPS policy alone causes a reduction in emissions, net of leakage, from the productive sectors within Colorado of 0.6 million tons of CO_2. This emissions reduction is achieved at the expense of a 0.12% loss in consumer welfare over the model period, compared to the business-as-usual case. Total in-state production of electricity declines by 0.13% by 2060, with conventional generation declining by a larger amount as renewable production increases. Electricity price increases peak at 0.09% above the baseline level in 2040.

Considering the emissions permit scenario while imposing no RPS, the model predicts consumption to fall by 4% while the price of consumption rises by 6%, (compared to the benchmark case). Permit prices rise from \$3.72 to \$167.35, indexed by the 2005 price of consumption, as the available quantity of permits is reduced. Some carbon-intensive sectors of the economy decline dramatically, such as electricity production and coal mining. These impacts continue beyond the model period due to the reduction in investment in later periods which helps to smooth consumption. This lack of investment reduces the capital stock and therefore economic growth for years beyond 2060.

More interesting is the comparison between the emissions permit scenario cases, with and without the addition of the RPS policy. Some interactions between these policies are desirable; for instance, permit prices and emissions leakage are reduced in early years. Several economic indicators are compared here under these policy scenarios.

4.1. Permit prices

Figure 2 gives permit prices with and without the RPS policy with a plot of the difference between them. When the RPS is added, emissions permit prices fall in the early years of the program. As the energy intensive electricity sector demands fewer emissions permits, prices are reduced. However, in the later years of the program, emissions permit prices are nearly the same as in the case of permits alone. There is no significant reduction in permit prices for the later years because of the large size of the emissions reduction and the investment requirements of the RPS. The capital investments required in early years in to meet the RPS are costly but do not help to meet the large emissions reduction required.



	2020	2025	2030	2035	2040	2045	2050	2055	2060
Permits alone	3.72	8.13	12.9	21.78	39.78	79.23	167.34	144.02	122.07
Permits + RPS	2.5	7.14	12.25	21.25	39.77	79.19	167.28	143.95	122.01
Difference	1.22	0.99	0.65	0.53	0.01	0.04	0.06	0.07	0.06
Percent change	-33%	-12%	-5%	-2%	0%	0%	0%	0%	0%

Figure 2: Permit prices with and without the RPS (\$/ton CO_2). The RPS lowers permit prices slightly until 2035 while it is binding.

4.2 Energy prices

Figure 3 displays prices for fuels coal, oil, and natural gas as well as electricity for the baseline case (allowing for renewable production) and with both the RPS and emissions permit policies. The prices shown are the Armington aggregate prices for fuels, indexed to 2005 levels. With the emissions permit policies in place, prices of fuels rise compared to the baseline level. This occurs because instate production of these fuels is reduced dramatically. While demand for fuels is also reduced, the production of fuels is carbon intensive, so local production of coal, oil, and gas are drastically reduced. The price of imports does not change, so the decline in local supply is experienced as a slight price increase within Colorado. Electricity prices increase as fuels become more expensive, permits are required, and demand increases. The price increase is limited because import prices are unchanged, but possible because imports and domestic production are not considered perfect substitutes according to Armington (1969).

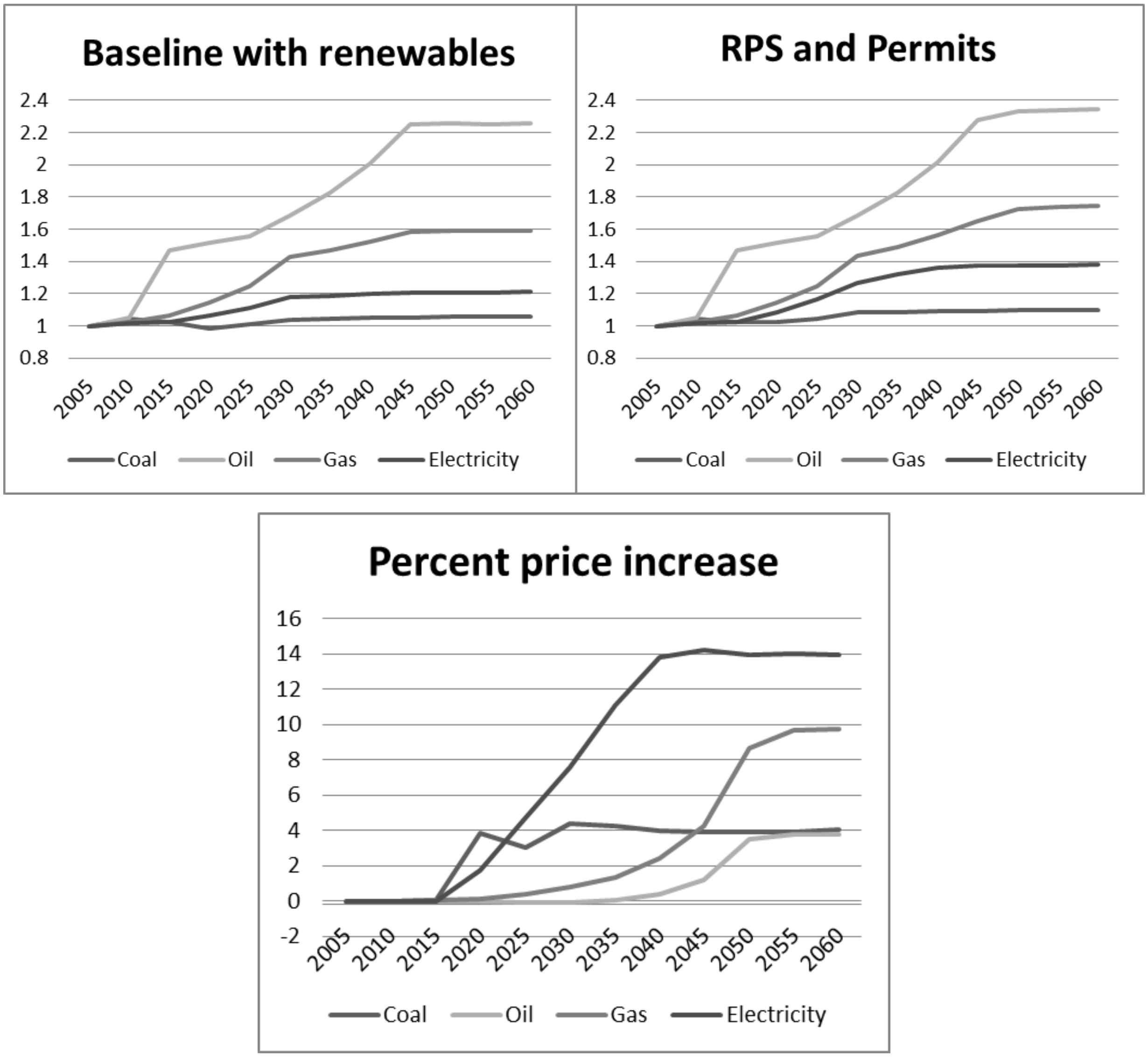


Figure 3: Normalized energy prices under policy scenarios. Adding the permit policy and the RPS causes energy prices to rise relative to the baseline case.

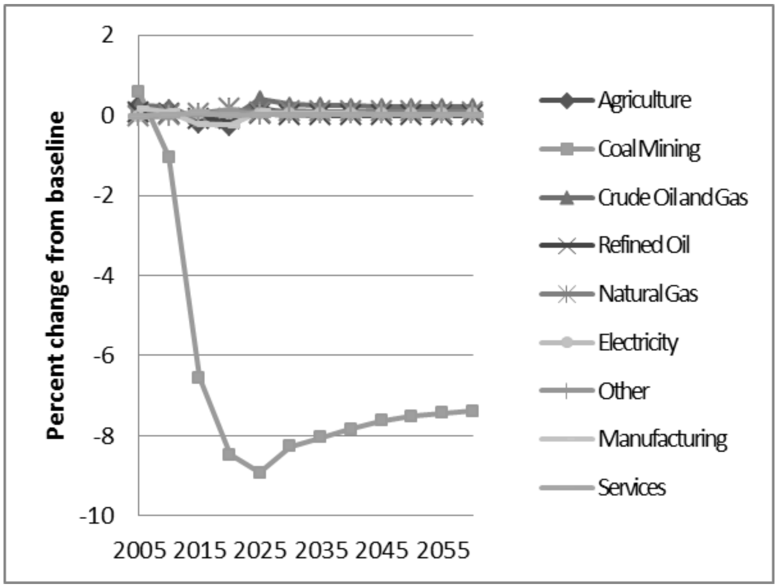


Figure 4: Changes in sectoral output from baseline under the RPS policy alone. The coal mining sector suffers the largest contraction relative to the baseline when the 20% RPS is achieved in 2020.

4.3 Sectoral output

As Figure 4 shows, the RPS policy does not dramatically change the output of commodities, with the exception of coal. Production of coal declines by up to 9% in 2025, as less coal is demanded by the traditional electricity sector. By adding the RPS to the permit policy, few additional changes are observed in sectoral output. With the RPS, coal production drops off faster than with the permits alone. The magnitude of the emissions reduction overwhelms the RPS policy, particularly in later periods.

The ELE production in Figures 4, 5, and 6 represents electricity produced by both traditional and renewable means. The share of electricity produced by these technologies differs under the policy scenarios, shown in Table 4. Table 3 gives the proportion of renewable electricity used by Colorado residents.

The shares of renewable electricity produced and used in Colorado differ depending on the amount of imports. In the baseline case (with no policy), renewable production increases over time as fuel inputs become more expensive, according to their projections. However, the proportion of renewable use remains lower than the level required by the RPS. When the RPS policy is added, it is therefore binding. If permits alone are used to reduce emissions, the proportion of renewables used increases dramatically, as traditional production and consumption of electricity are reduced. When the RPS and permits are used together, the RPS is binding until 2030, after which the increasing emissions reduction forces the RPS to be exceeded. Renewable use matches that under the permit system alone, and renewable production is driven to 100% of the total electricity use.

Year	No policy	RPS alone	Permits alone	Permits and RPS	RPS requirement
2005	9	9	9	9	N/A
2010	9.23	10	9.22	10	10
2015	9.58	15	9.57	15	15
2020	9.81	20	10.49	20	20
2025	10.07	20	12.26	20	20
2030	10.31	20	15.57	20	20
2035	10.33	20	21.82	21.81	20
2040	10.35	20	35.04	35.04	20
2045	10.38	20	44.16	44.17	20
2050	10.4	20	53.27	53.27	20
2055	10.4	20	58.62	58.63	20
2060	10.41	20	64.09	64.1	20

Table 3: Share of renewable electricity use under policy scenarios (in percent). Renewable use increases in the baseline due to increasing energy prices (according to EIA projections). The RPS is binding in all years when used alone, and in early years when used with the emissions permit system.

Year	No policy	RPS alone	Permits alone	Permits and RPS	RPS requirement
2005	9	9	9	9	N/A
2010	9.25	10.11	9.25	10.11	10
2015	9.64	15.65	9.64	15.65	15
2020	9.9	21.23	10.72	21.53	20
2025	10.18	21.23	13.01	22.36	20
2030	10.45	21.21	18.09	24.03	20
2035	10.44	21.94	30.28	30.22	20
2040	10.43	20.73	76.21	76.21	20
2045	10.45	20.57	100	100	20
2050	10.45	20.45	100	100	20
2055	10.45	20.35	100	100	20
2060	10.44	20.27	100	100	20

Table 4: Share of renewable electricity production under policy scenarios (in percent). Renewable production increases in the baseline due to increasing energy prices (according to EIA projections). In the permit cases, traditional electricity generation is eliminated by 2045.

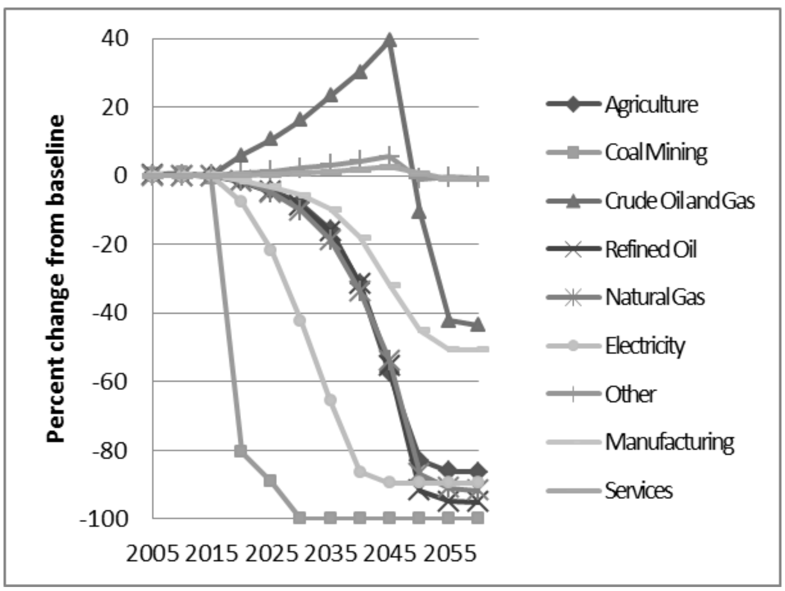


Figure 5: Changes in sectoral output from baseline under the permit policy alone. Coal output declines, as it is a carbon-intensive sector and the electricity sector reduces its demand for coal. By the end of the period, all electricity produced in Colorado is generated by renewables. The low-carbon services sector increases compared with the baseline. Increased exports of crude oil help to finance the increase in imports of other goods.

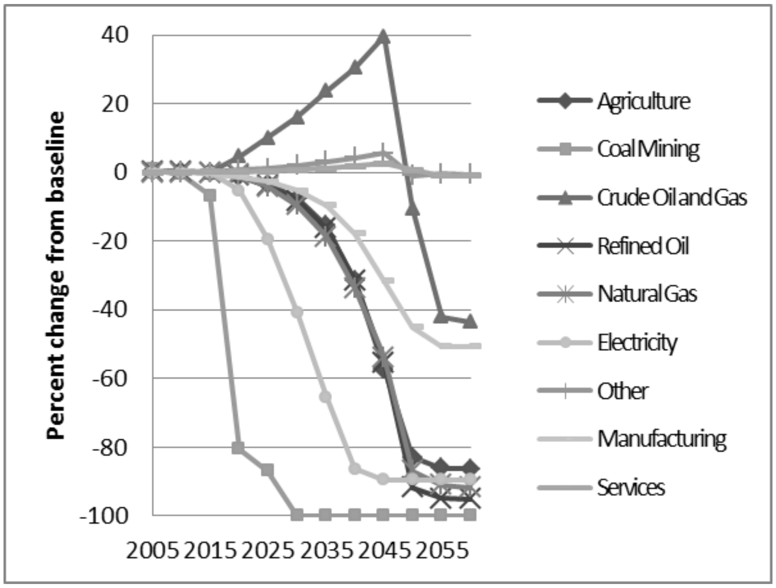


Figure 6: Changes in sectoral output from baseline under both the RPS and permit policies. Compared to the case with no RPS, the coal mining sector begins its contraction earlier.

4.4 Economic indicators

Percentage changes in macroeconomic indicators (from the baseline) are displayed in Figures 7, 8, and 9. For the RPS alone, investment, and therefore the capital stock increases, compared to the baseline. New capital is needed to facilitate an increase the production of renewable electricity, and because this capital is sector specific, investments in mobile capital also increase to maintain the mobile capital stock. The percentage change in consumption is insignificant.

Using the permit and RPS policies together only changes the outcome of the permit system in the early years of the program, when the emissions reductions are small and the RPS is binding. In these years, investment and the capital stock are larger than in the case with permits alone.

Consumer welfare changes under the policy scenarios are given in Table 5. These percentages represent the percent equivalent variation, or percent of present value of consumption that consumers would pay to avoid the policy, over the period 2005-2060. Further reductions in welfare may be experienced beyond 2060, compared to the baseline, due to the decreased capital stock at the end of the model period. Using the RPS policy decreases consumer welfare slightly, compared to the baseline, as capital is allocated in a less efficient way than in the benchmark case. Using a permit scheme results in a larger decrease in welfare as the magnitude of the policy shock is much larger. Using both policies further decreases consumer welfare, because the RPS is binding in early years, causing sub-optimal capital investment.

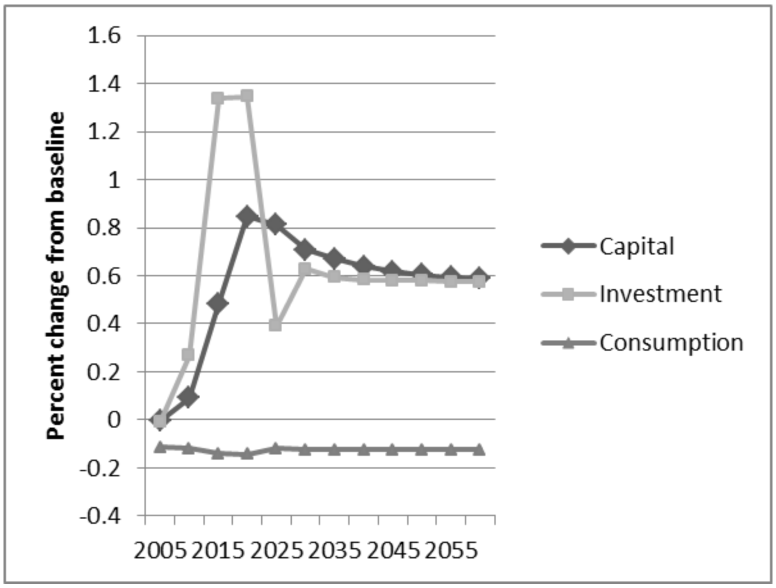


Figure 7: Changes in economic indicators from benchmark under the RPS policy alone (in percent). An increase in investment is needed to build the renewable capital stock.

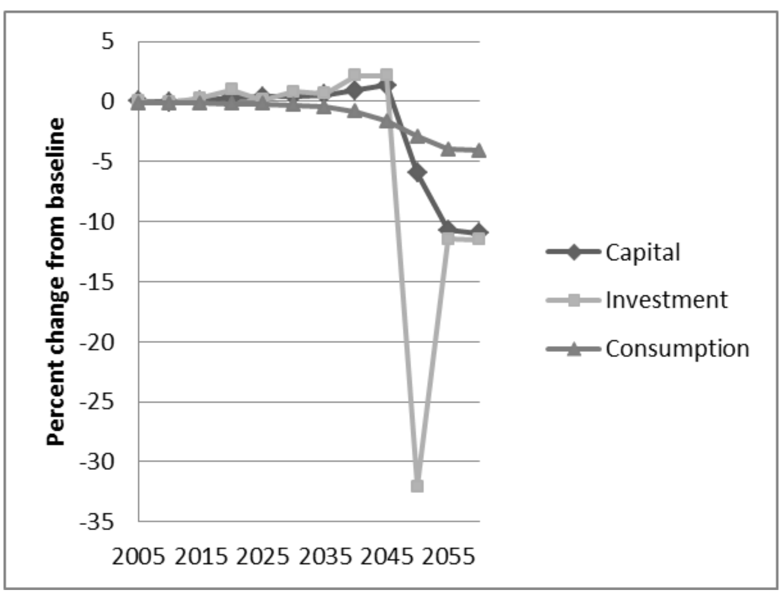


Figure 8: Changes in economic indicators from benchmark under the permit policy alone. Investment falls (relative to the baseline) in 2050 to allow for consumption smoothing.

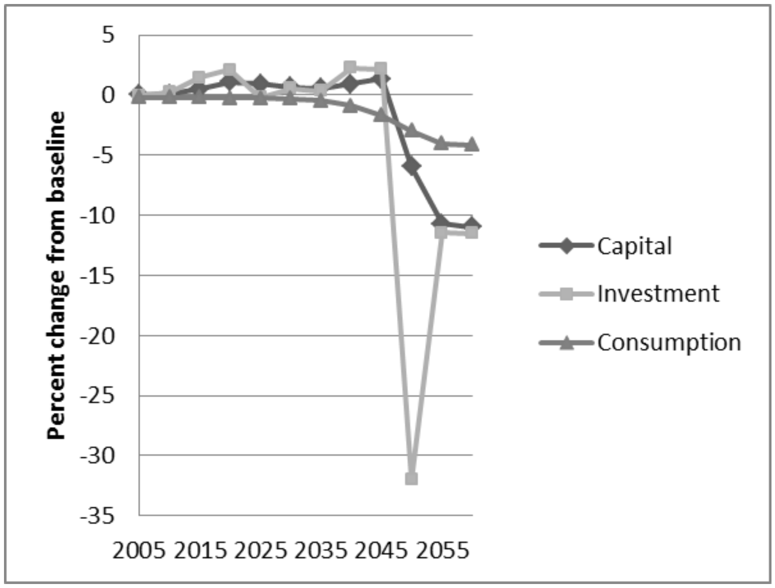


Figure 9: Changes in economic indicators from benchmark under both the RPS and permit policies. An increase in investment is needed in early years to build the renewable capital stock. Investment falls (relative to the baseline) in 2050 to allow for consumption smoothing.

This measure of welfare does not account for the benefits of the policy. While the emissions reduction achieved by Colorado is too small to affect atmospheric concentration of GHG's, other localized pollutants may be reduced by switching out of fossil fuel electricity generation. Colorado residents may also receive some benefit from the sense of accomplishment gained by reducing emissions. These benefits are not captured in the utility function. Furthermore, as shown in Table 6, adding the RPS leads to an additional net reduction in emissions due to the reduction in emissions leakage.

Policy scenario	Change in welfare from benchmark	Cumulative emissions 2005 - 2060, MMT CO_2 (net of leakage)
RPS alone	-0.12	1286
Permits alone	-0.62	672
RPS and permits	-0.68	672
Additional emissions reduction from RPS alone		0.6 MMT CO_2
Additional emissions reduction from RPS with permits		0.8 MMT CO_2

Table 5: Changes in consumer welfare (in percent equivalent variation (EV)) over the period 2005 - 2060. The percent EV is the percent of the present value of consumption the consumer would pay to avoid the policy. For comparison, the cumulative emissions, net of emissions leakage, generated by Colorado over the model period is presented. By reducing emissions leakage, the addition of the RPS produces a small reduction in emissions, with or without the emissions constraint.

4.5 Leakage rates

Table 6 presents emissions leakage rates for the electricity sector and the overall economy under the permit policy with and without the RPS. RPS policies are touted as a way to reduce emissions without simply exporting these emissions to other jurisdictions. This benefit should be seen as a decrease in leakage rates when this policy is used as part of a scheme to reduce emissions. In this case, emissions leakage is reduced in those years when the RPS is binding. The RPS requires investment in renewable electricity generation occur earlier in the period. This additional renewable electricity replaces some of the imports that would be required with the permit system alone.

We assume that the renewable capacity required to meet the RPS will be built within Colorado. This assumption is reasonable because imports of renewable power are limited, and new capacity must be built in order to meet the state's demand. Also, the legislation provides incentives for this new capacity to be built within Colorado, specifically allowing each KWh produced in Colorado to be counted as more than one KWh. These incentives ensure that Colorado will meet a large portion of its requirements for renewables within the state.

Year	Electricity Permits alone	Electricity Permits and RPS	Economy-wide Permits alone	Economy-wide Permits and RPS
2020	15.2	9.0	11.0	10.0
2025	18.4	15.4	9.9	9.0
2030	21.0	19.9	10	9.7
2035	21.6	21.5	9.5	9.5
2040	20.5	20.5	8.3	8.3
2045	15.2	15.2	5.8	5.8
2050	9.3	9.3	3.3	3.3
2055	7.4	7.4	2.7	2.7
2060	5.7	5.7	2.2	2.2

Table 6: Leakage rates (in percent) under different policy scenarios. Adding the RPS reduces the emissions leakage in the years when it is binding.

As a result of the decrease in leakage for the electricity sector, leakage rates decrease for the overall economy when the RPS is added. Other sectors still experience positive leakage rates as electricity and fuels become more expensive within Colorado (as shown in Figure 3). While the RPS cannot be met solely by reducing electricity production, it can be met by reducing use accordingly. The incentive remains for emissions-intensive industries to relocate.

5 Conclusions

Colorado's RPS policy is designed to reduce CO_2 emissions while encouraging growth in the renewable sector, while limiting the leakage of emissions to other states. The effectiveness of the RPS at limiting the economic impacts and emissions leakage from an overall emissions reduction target depend on the size of the reduction being undertaken. When reduction goals are small, the RPS succeeds at reducing emissions permit prices and emissions leakage by limiting electricity imports, encouraging otherwise uneconomical technology, and replacing emissions intensive production with the burgeoning clean energy industry. However, as the emissions reductions goals become larger, renewable technology becomes economical on its own. Traditional generation, mostly using carbon-intensive coal, is drastically reduced within Colorado, and this power is imported. Leakage rates are no longer lower than without the RPS policy, and the system is slightly more costly for consumers over the policy horizon.

A few noteworthy assumptions govern the accuracy of these estimates. The energy price and output forecasts, and the emissions forecasts, generated by the EIA include some amount of substitution into renewable production that is not included in the model. This may lead the results presented here to overestimate the impacts of emissions reduction policy. On the other hand, the small open economy assumption allows Colorado residents to import electricity without limits to transmission capacity and availability of supply. These limits will cause an overestimate of leakage rates, and an underestimate of electricity prices and coal production. Advances in technology not captured by this model can also help to meet the state's emissions goal. Finally, with national and regional policy on the horizon, emissions leakage concerns become less significant for small jurisdictions, except where these areas choose more stringent targets.

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