A Prospective Analysis of the Costs, Benefits, and Impacts of U.S. Renewable Portfolio Standards

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Preface

This is one report in a series that explores the costs, benefits, and other impacts of state renewable portfolio standards (RPS), both retrospectively and prospectively. The first report, *A Survey of State-Level Cost and Benefit Estimates of Renewable Portfolio Standards*, published in 2014, comprehensively summarized historical RPS compliance costs, drawing in part on estimates developed by utilities and state regulatory agencies. The study also reviewed analyses of the broader societal benefits and impacts of several states' RPS policies, typically conducted for or by the regulatory agencies or RPS administrators in those states. However, the small number of such studies, and their widely varying methods and scopes, ultimately limited the ability to compare benefits across states or to generalize beyond the specific studies performed. That limitation set the stage for future reports.

The second report in the series, *A Retrospective Analysis of the Benefits and Impacts of U.S. Renewable Portfolio Standards*, published in January 2016, analyzed historical benefits and impacts of renewable energy (RE) used to meet all state RPS policies, in aggregate, employing a consistent and well-vetted set of methods and data sets. The analysis focuses on three specific benefits: air pollution, greenhouse gas emissions, and water use. It also analyzes three other impacts: gross job additions, wholesale electricity market price suppression, and natural gas price suppression. These are an important subset, but by no means a comprehensive set, of all possible effects associated with RPS policies. That report did not include a comparison of costs and benefits of renewables used to meet RPS policies, and nor did it assess the potential costs, benefits, and impacts prospectively based on future increases in RPS targets.

The present report fills that gap by evaluating the future costs, benefits, and other impacts of renewable energy used to meet current state RPS polices. It also examines a future scenario where RPSs are expanded. The analysis examines changes in electric system costs and retail electricity prices, which include all fixed and operating costs, including capital costs for all renewable, non-renewable, and supporting (e.g., transmission and storage) electric sector infrastructure; fossil fuel, uranium, and biomass fuel costs; and plant operations and maintenance expenditures. The analysis uses the same framework as the second report to analyze three specific benefits: air pollution, greenhouse gas emissions, and water use. It also analyzes two other impacts, RE workforce and economic development, and natural gas price suppression.

The terminology applied in this series does not align precisely with the traditional concepts of costs and benefits, but rather is a function of how RPS programs have often been evaluated in practice. This analysis series, particularly the present report, evaluates renewable energy used to meet RPS policies in terms of costs, benefits, and other impacts:

- *Cost metrics* presented in this report include national electric system expenditures and national and regional retail electricity prices. Previous reports examined the cost of compliance from the perspective of the utility or other load-serving entity, compared to the costs that would have been borne in the absence of the RPS.
- *Benefits*, as analyzed in this report series, consist specifically of environmental and health benefits that accrue to society at large, rather than to individual utilities. In theory, such benefits may be negative, representing net environmental costs, if the renewable electricity used for RPS compliance leads to more harmful environmental impacts than it avoids. These benefits have been of interest to state policymakers as they adopt RPS polices.
- Other impacts, in the form of resource transfers from one market participant or segment to another, are also evaluated. These impacts may also entail net costs or benefits to society at large, but our analyses focus only on the gross impacts, not the net cost or benefit.

The present report is intended to help policymakers, RPS administrators, and other decision makers gauge the potential significance of the costs as well as a number of key benefits and impacts from state RPS programs.

Acknowledgments

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Acronyms

AP2	Air Pollution Emission Experiments and Policy (analysis model)
Btu	British thermal unit
CO_2	carbon dioxide
CPP	Clean Power Plan
DOE	U.S. Department of Energy
EASIUR	Estimating Air pollution Social Impacts Using Regression model
EIA	U.S. Energy Information Administration
EPA	U.S. Environmental Protection Agency
GHG	greenhouse gas
GW	gigawatt
IWG	Interagency Working Group
JEDI	Jobs and Economic Development Impacts model
kW	kilowatt
kWh	kilowatt-hour
LSE	load-serving entity
MW	megawatt
MWh	megawatt-hour
NO_x	nitrogen oxides
NREL	National Renewable Energy Laboratory
O&M	operations and maintenance
PM	particulate matter
RE	renewable energy
REC	renewable energy certificate
ReEDS	Regional Energy Deployment System
RGGI	Regional Greenhouse Gas Initiative
RPS	renewable portfolio standard
SCC	social cost of carbon
SO_2	sulfur dioxide
TWh	terawatt-hour

Executive Summary

As states have gained experience with renewable portfolio standards (RPS) policies, many have made significant revisions to existing programs. In 2015 and 2016, seven states raised and extended their final RPS targets, while another state enacted a new RPS policy (Barbose 2016b). Interest in expanding and strengthening state RPS programs may continue, while efforts like recent proposals in many states to repeal or freeze existing RPS policies may also persist. In either context, questions about the potential costs, benefits, and other impacts of RPS programs are usually central to the decision-making process.

This report follows on previous analyses that have focused on the historical costs, benefits, and other impacts of existing state RPS programs (Heeter et al. 2014; Wiser et al. 2016a). This report examines RPS outcomes prospectively, considering both current RPS policies as well as a potential expansion of those policies. The goal of this work is to provide a consistent and independent analytical methodology for that examination. This analysis relies on National Renewable Energy Laboratory's (NREL's) Regional Energy Deployment System (ReEDS) model to estimate changes to the U.S. electric power sector across a number of scenarios and sensitivity cases, focusing on the 2015–2050 timeframe. Based on those modeled results, we evaluate the costs, benefits, and other impacts of renewable energy contributing to RPS compliance using the suite of methods employed in a number of recent studies sponsored by the U.S. Department of Energy (DOE): a report examining retrospective benefits and impacts of RPS programs (Wiser et al. 2016a), the *Wind Vision* report (DOE 2015), the *On the Path to SunShot* report focusing on environmental benefits (Wiser et al. 2016b), and the *Hydropower Vision* report (DOE 2016).

The analysis is structured around three scenarios: a No RPS scenario, which assumes RPSs do not exist beyond 2014 and limited economic growth in renewable energy (RE); an Existing RPS scenario, which assumes RPS requirements continue to grow based on existing state RPS policies as of July 2016; and a High RE scenario, which assumes that nearly all states adopt an RPS with relatively aggressive targets. In this analysis, we estimate the costs, benefits, and other impacts of higher levels of renewable energy by analyzing the Existing RPS and High RE scenario results relative to those from the No RPS scenario. This approach is used to measure the costs, benefits, and impacts of the RE generation used to meet RPS policies. There are multiple drivers of new renewable energy—including other policies such as tax incentives and non-policy drivers—and we do not seek to attribute all of the estimated costs, benefits, and impacts solely to the RPS policies themselves. With that in mind and based on this approach, the key findings of the analysis are as follows and summarized in Figures ES-1 and ES-2.

Renewable Generation: In the Existing RPS scenario, renewables (including hydro) reach 26% of total U.S. electricity generation by 2030 and 40% by 2050, compared to 21% and 34% under the No RPS scenario. Under the High RE scenario, renewables reach 35% by 2030 and 49% by 2050. Because RE generation is greater in the Existing RPS and High RE scenarios than in the No RPS scenario, fossil fuel-based generation is correspondingly lower.

Costs: We estimate incremental costs, relative to the No RPS scenario, in terms of both the net present value of electric system costs over 2015–2050 and the difference in retail electricity prices. Both measures of costs are evaluated over a set of sensitivity cases related to future natural gas prices and renewable technology costs. Both measures consider fuel costs, operations and maintenance (O&M) costs, and capital costs for new generation, storage, and transmission infrastructure.

- **Electric System Costs**: For the Existing RPS scenario, incremental system costs (2015–2050) range from ±\$31 billion (-0.7% to 0.8% of the No RPS total system costs) across the sensitivity cases. On a levelized basis, these costs equate to about ±0.75¢ per kilowatt-hour of renewable energy (kWh-RE).

In the High RE scenario, incremental system costs range from \$23 billion (0.6%) to \$194 billion (4.5%), which equates to an incremental levelized cost ranging from 0.26¢/kWh-RE to 1.5¢/kWh-RE.

- **Electricity Prices**: Across the various sensitivity cases and census regions, retail electricity prices in the Existing RE scenario are up to a maximum of roughly 1¢/kWh higher than electricity prices in the No RPS scenario. However, estimated incremental prices vary significantly between regions and years and depend on future RE technology costs and fossil fuel prices. For some sensitivity cases and regions, we find that electricity prices are lower in the Existing RPS scenario than in the No RPS scenario. The High RE scenario has a considerably higher upper bound to the range of possible electricity price increases, with up to a 4.2¢/kWh increase in the most expensive case. Under certain conditions, however, even the High RE case may result in electricity price reductions in some regions and years.

Benefits: The study evaluates benefits associated with reduced air pollutant emissions and avoided human health damages, reduced greenhouse gas (GHG) emissions and avoided climate change damages, and reduced water use for electric power generation. These benefits are associated with all RE used to meet the RPS requirements and not with the RPS policies specifically.

- **Air Quality Benefits:** Cumulative (2015–2050) national emissions of sulfur dioxide (SO_2), nitrogen oxides (NO_x), and fine inhalable particles with diameters that are generally 2.5 micrometers and smaller ($PM_{2.5}$) decrease by 5.5%, 5.7%, and 4.5%, respectively, in the Existing RPS scenario. As a result of these reductions, we estimate the health and environmental benefits of the Existing RPS scenario to be equal to \$97 billion using a "central" estimate, equivalent to 2.4¢/kWh-RE. For the High RE scenario, we estimate cumulative emission reductions of 29% for each of the three air pollutants assessed (SO_2, NO_x, and $PM_{2.5}$), resulting in health and environmental benefits of \$558 billion using the central estimate, equivalent to 5.0¢/kWh-RE. In both scenarios, air quality benefits come primarily from avoided premature mortality, particularly in eastern United States.
- **Reductions in GHG Emissions**: Cumulative (2015–2050) life-cycle GHG emissions decrease by 6% in the Existing RPS scenario, which translates into \$161 billion of global benefits when applying a "central value" for the social cost of carbon. These global benefits equal 3.9¢/kWh-RE. In the High RE scenario, cumulative life-cycle GHG emissions decrease by 23%, resulting in \$599 billion of global benefits when using the central value for the social cost of carbon, equivalent to 5.4¢/kWh-RE.
- **Water Use Reduction:** Cumulative water consumption in the Existing RPS scenario is 4% lower and water withdrawals are 3% lower compared to the No RPS scenario. On average, we find that each megawatt-hour of renewable energy used to meet Existing RPS targets saves withdrawal of 3,400 gallons of water and consumption of 290 gallons of water.[1] In the High RE scenario, water consumption and withdrawals are both 18% lower. To put these figures in context, the 2030 annual consumption savings are equal to the water demands of 420,000 U.S. households in the Existing RPS scenario, and 1.9 million households in the High RE scenario. Many U.S. regions, including water-stressed regions, see water savings. We do not estimate the monetized water savings benefits because no standard valuation methods exist.

[1] Withdrawals are defined as the amount of water removed or diverted from a water source for use, while consumption refers to the amount of water that is evaporated, transpired, incorporated into products or crops, or otherwise removed from the immediate water environment.

Impacts: The study evaluates two other "impacts," which are best considered resource transfers rather than societal benefits.

- **RE Workforce Requirement and Economic Development**: The Existing RPS scenario requires 4.7 million full-time job-years in RE-related employment, about a 19% increase over the 2015 to 2050 study period compared to the No RPS scenario. The High RE scenario requires in 11.5 million job-years of RE-related employment, or a 47% increase from the No RPS scenario. Gross RE jobs include onsite, supply chain, and induced jobs. Gross onsite jobs, which include construction and O&M jobs, represent 28% and 29% of all gross jobs, respectively, in the Existing RPS and High RE scenarios. We do not estimate economy-wide net impacts, and the increased RE jobs noted here will be offset by job contraction in other parts of the economy.
- **Natural Gas Price Reductions:** Achieving the Existing RPS and High RE scenarios reduces cumulative (2015–2050) electricity-sector natural gas demand by a total of 35 quads and 46 quads, respectively, relative to the No RPS baseline. These reductions represent 3.3% and 4.3% of total projected economy-wide natural gas consumption in the United States over the same period, and tend to suppress natural gas prices. As a result, natural gas consumer bill savings outside the electric sector from the Existing RPS scenario total $78 billion on a discounted, present-value basis, which is equal to a levelized impact of 1.9¢/kWh-RE. Under the High RE scenario, total consumer savings equal $99 billion, or 0.9¢/kWh-RE. These savings come at the expense of producers, and therefore do not represent societal net benefits but rather resource transfers.

		EXISTING RPS		HIGH RE	
RENEWABLE ENERGY IN 2050		increased by ↑ 122 GW	296 TWh	increased by ↑ 331 GW	765 TWh
COSTS	ELECTRIC SYSTEM COSTS	range from -0.7% to 0.8%	equivalent to +/– $31 billion (estimates span +/- 0.75¢/kWh-RE)	range from 0.6% to 4.5%	equivalent to $23 billion– $194 billion (estimates span 0.26-1.5¢/kWh-RE)
COSTS	ELECTRICITY PRICES	range from -2.4 cents/kWh to 1 cent/kWH		range from -1.9 cents/kWh to 4.2 cents/kWH	
BENEFITS	SULFUR DIOXIDE	reduced by ↓ 6%; 2.1 million metric tons SO_2	equivalent to $97 billion (2.4¢/kWh-RE) (estimates span $48 billion-$175 billion (1.2-4.2¢/kWh-RE))	reduced by ↓ 29%; 11.1 million metric tons SO_2	equivalent to $558 billion (5.0¢/kWh-RE) (estimates span $303 billion-$917 billion; 2.7-8.2¢/kWh-RE)
BENEFITS	NITROGEN OXIDES	reduced by ↓ 6%; 2.5 million metric tons NO_x		reduced by ↓ 29%; 12.8 million metric tons NO_x	
BENEFITS	PARTICULATE MATTER 2.5	reduced by ↓ 5%; 0.3 million metric tons $PM_{2.5}$		reduced by ↓ 29%; 1.8 million metric tons $PM_{2.5}$	
BENEFITS	GREENHOUSE GAS EMISSIONS	reduced by ↓ 6%; 4.7 billion metric tons CO_2e	equivalent to $161 billion (3.9¢/kWh-RE) (estimates span $37 billion-$487 billion (0.9-11.8¢/kWh-RE))	reduced by ↓ 23%; 18.1 billion metric tons CO_2e	equivalent to $599 billion (5.4¢/kWh-RE) (estimates span $132 billion-$1,821 billion (1.2-16.3¢/kWh-RE))
BENEFITS	WATER USE	reduced by ↓ 4% consumption; 3% withdrawal		reduced by ↓ 18% consumption; 18% withdrawal	
IMPACTS	NATURAL GAS	reduced by ↓ 35 quads (3.3%)	equivalent to $78 billion impact 1.9¢/kWh-RE	reduced by ↓ 46 quads (4.3%)	equivalent to $99 billion impact 0.9¢/kWh-RE
IMPACTS	RE JOB NEEDS	increase in ↑ 19% RE-employment	equivalent to 4.7 million RE job-years	increase in ↑ 47% RE-employment	equivalent to 11.5 million RE job-years

Figure ES-1. Cost, benefits, and impacts of the Existing RPS scenario relative to the No RPS Scenario, 2015–2050

When comparing the costs and monetized benefits, we find that the benefits exceed the costs, even when considering the highest cost and lowest benefit outcomes (Figure ES-2). Under the Existing RPS scenario, the high-end costs are 0.75¢/kWh-RE, while air pollution and health benefits total at least 1.2¢/kWh-RE and GHG benefits total at least 0.9¢/kWh-RE. Under the High RE scenario, the high end costs are 1.5¢/kWh-RE while air pollution and health benefits total at least 2.7¢/kWh-RE and GHG benefits total at least 1.2¢/kWh-RE. The figures here are presented on a national basis and reflect levelized 2015–2050 values.

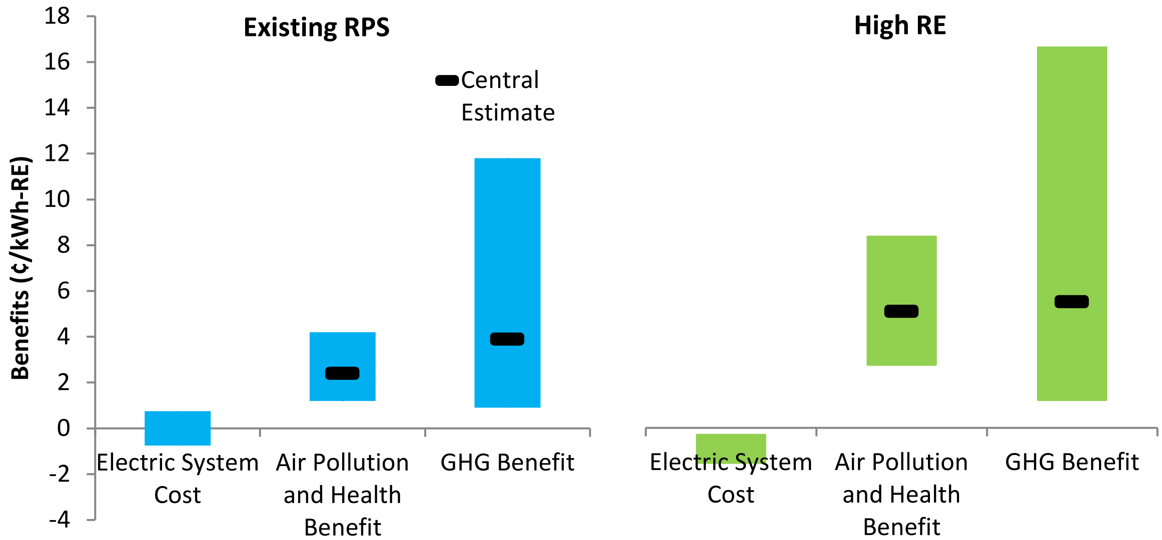

Figure ES-2. Comparison of national systems costs and monetized benefits under the Existing RPS and High RE scenarios

Note: Positive values reflect benefits in the Existing RPS and High RE scenarios, whereas negative values reflect higher costs relative to the No RPS scenario. Water benefits, gross RE job needs and economic impacts, and natural gas impacts are not shown here.

Our analysis has several limitations. First, we recognize that there may be more cost-effective ways than RPS policies to achieve the benefits and impacts discussed. Second, while our analysis examines the RE needed to meet RPS demand growth going forward, it does not seek to *attribute* those effects solely to RPS policies. In other words, the estimates provided reflect an upper bound to the impacts *of the policies themselves* because other drivers might lower the influence of RPS policies in adding new RE. Third, our work distinguishes between the potential benefits and impacts of RPS programs. Impacts are best considered resource transfers, benefiting some stakeholders at the expense of others, though such impacts might still be relevant considerations when evaluating state RPS programs. We do not evaluate the *net* effects of these impacts and, as such, cannot assess whether or not these impacts reflect net costs or benefits at a national scale. Fourth, we consider the impacts of RE needed to meet all existing (and expanded) RPSs in aggregate and do not estimate the impacts of any individual RPS policy. Finally, our analysis considers an important subset of—but not all—potential benefits and impacts; for example, we do not quantify land use and wildlife impacts. Despite these limitations, the analysis can inform decision makers about the prospective costs, merits, and value of state RPS programs as they consider revisions to existing policies and development of new policies.

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1. Introduction

Background

State renewable portfolio standards (RPS), which require that electric load-serving entities (LSEs) meet a minimum portion of their load with eligible forms of renewable electricity (RE), currently exist in 29 U.S. states and Washington, D.C. (Figure 1.1). Along with federal tax credits and other state policies, RPS programs have been one of the key policy drivers for RE growth in the United States, with more than half of all renewable capacity additions since 2000 serving RPS demand (Barbose 2016a). State RPS requirements are scheduled to continue ramping up over time, with most states reaching their maximum targets between 2020 and 2025, though eight states have targets that increase until 2030 or beyond. Under existing policies, aggregate RPS requirements will roughly double from 2015 to 2030, reaching 10% of total U.S. retail electricity sales by 2030 (Barbose 2016b).

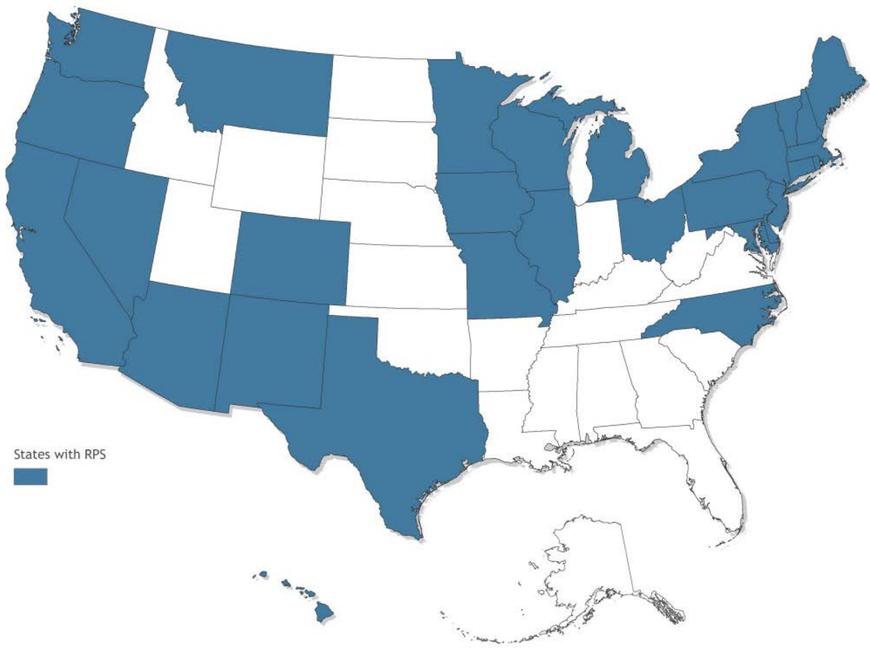


Figure 1.1. States with RPS policies as of November 2016

As states have gained experience with RPS policies, many have made significant revisions to existing programs, including increases to their final targets. In 2015 and 2016, seven states raised and extended their final RPS targets, while another enacted a new RPS policy (Barbose 2016b).[2] Interest in expanding and strengthening state RPS programs may continue, while efforts like recent proposals in many states to repeal or freeze existing RPS policies may also persist. In either context, questions about the potential costs, benefits, and other impacts of RPS programs are usually central to the decision-making process.

A variety of sources—including several prior studies in the same series as this report—provide insight into the historical costs, benefits, and other impacts of RPS programs.[3] LSEs in many states are required to submit compliance cost data to state regulatory agencies, which often issue annual RPS compliance cost reports. Although the definitions and methods used to calculate RPS compliance costs can vary

[2] California, Connecticut, Hawaii, Michigan, Oregon, Rhode Island, and Washington, D.C. raised and extended their targets; Vermont enacted a new RPS.

[3] Previous studies include Wiser et al. (2016a), Barbose et al. (2015), and Heeter et al. (2014).

across states, total reported costs in 2014 were $2.6 billion, equivalent to 1.3% of retail electricity bills in RPS states (Barbose 2016a). Compliance costs vary considerably across states, and are generally increasing over time as states' targets ramp up (Heeter et al. 2014). A number of econometric analyses have also estimated the net effect of state RPS policies on average retail electricity prices at the state or utility level, with results across the studies ranging from a 3% to 7% increase (Morey and Kirsch 2013; Tra 2016; Wang 2015). Compliance cost data and econometric analyses of the effects on retail electricity prices both reflect net costs to LSEs or electric customers, but do not reflect broader costs and benefits.

A small number of states have commissioned analyses of broader environmental or other societal benefits of their RPS programs, though these studies have widely varying methods and scopes and thus offer limited opportunities to synthesize their findings (Heeter et al. 2014). Responding to that need, Wiser et al. (2016a) developed the first-ever national assessment of the benefits and impacts of state RPS programs, focusing on the year 2013. The study estimated $7.4 billion in benefits from reduced climate change and air pollution damages, along with additional benefits from reduced water consumption. The study also estimated that RPS policies in 2013 helped support roughly 200,000 gross jobs related to renewable energy (RE), and led to $1.3 billion to $4.9 billion in consumer savings from reduced electricity and natural gas prices.

Notwithstanding the insights gained from these various prior studies, two important gaps remain in terms of informing future policy development. The first is to provide a forward-looking perspective, considering currently scheduled increases in RPS targets as well as the incremental effects of possible revisions to those targets. The second is to estimate both costs and benefits in an integrated manner to allow direct comparison. The present study is intended to address both of these gaps.

Scope, Methods, and Contribution

This study evaluates the costs, benefits, and other impacts of all RE needed to meet RPS demand growth through 2050, under both existing RPS policies as well as possible expansions. Estimated costs include all electric infrastructure and operating costs and are measured in terms of both the net present value of electric system expenditures as well as changes to average electricity prices. Net costs to the electric system are evaluated under a range of sensitivity cases related to natural gas prices and RE technology costs. Broader societal benefits and impacts evaluated within the study include: reduction in greenhouse gas (GHG) emissions, reduction in air pollution emissions, reduction in water use, development of jobs, economic development, and natural gas price suppression. As discussed below, the latter three items are best considered "impacts" rather than strict societal benefits in the context of this analysis. For each benefit and impact, we quantify effects in physical units (e.g., tons of pollutants, gallons of water) and, where possible, monetize them into dollar-value terms and quantify uncertainty. In presenting results, we focus on the aggregate effects of RPS programs nationally and regionally; we do not analyze the costs and benefits of individual state RPS programs.

The analysis of costs, benefits, and impacts is structured around three scenarios: Existing RPS, High RE, and No RPS. The **Existing RPS** scenario assumes RPS requirements continue to grow based on state RPS policies as of July 2016.[4] Additional economic growth in RE above and beyond what is needed to meet RPS requirements also takes place in the Existing RPS scenario. The **High RE** scenario represents a hypothetical scenario in which all states adopt an RPS with expanded targets. The **No RPS** scenario assumes RPSs do not exist beyond 2014. Continued economic additions of RE take place under the No

[4] This cut-off date was a function of the timing of the analysis. As a result, the analysis does not account for the increase and extension to New York's RPS of 50% by 2030, up from 29% by 2015 (adopted in August 2016) or any other changes since July 2016.

RPS scenario, but RE additions are capped at the levels seen in the Existing RPS scenario. Further details are described in Section 2.

The study relies on a suite of models and analytical techniques, described in detail in Section 2. We use the National Renewable Energy Laboratory's (NREL's) Regional Energy Deployment System (ReEDS) and dSolar models to estimate differences in generation, capacity, fuel use, water use, emissions, and costs under each scenario and sensitivity case. Based on those ReEDS outputs, individual benefits and impacts are then estimated using methods developed and vetted through a number of earlier U.S. Department of Energy (DOE) reports. These include the prior report in this series focusing on retrospective benefits and impacts (Wiser et al. 2016a), as well as the *Wind Vision Report* (DOE 2015), the *On the Path to SunShot* report focusing on environmental benefits (Wiser et al. 2016b), and the *Hydropower Vision* report (DOE 2016). Moreover, the scenario construct in our analysis is consistent with these earlier studies wherein we evaluate differences in a scenario with higher levels of renewable generation and a baseline scenario where renewable generation is capped.

This report represents the first national-level, integrated assessment of the prospective costs, benefits, and impacts of state RPS policies. However, we are not alone in analyzing related topics. Individual states often collect and publish historical data on RPS compliance costs, and several states have evaluated broader benefits and impacts (Heeter et al. 2014). Various researchers have applied statistical methods to try to isolate the historical effects of RPS programs on specific policy-relevant criteria, such as GHG emissions (Eastin 2014; Yi 2015), air pollution (Eastin 2014; Werner 2014), jobs (Bowen et al. 2013; Yi 2013), and retail electricity prices (Caperton 2012; Johnson 2014; Morey and Kirsch 2013; Tra 2016; Wang 2015). In addition, a previous study in this series provided a national-level assessment of historical benefits and impacts (Wiser et al. 2016a).

Among studies that have taken a prospective look, many states estimated future RPS costs prior to initial enactment of their RPS, as summarized by Chen et al. (2007). Prospective cost-effectiveness evaluations for several states have also been conducted in concert with major revisions to state RPS programs (e.g., Rouhani et al. 2016). Prospective studies with a national scope have focused primarily on the potential effects of a national RPS or clean energy standard (EIA 2012; Goulder et al. 2016; Logan et al. 2009; Mignone et al. 2012; Paul et al. 2014). To date, however, we are aware of no prior work that has sought to prospectively evaluate the cost and benefits of all state RPS programs in aggregate.

General Limitations

Caveats and limitations associated with individual analytical elements in this study are discussed in Section 2. In addition to those, a number of general, cross-cutting considerations deserve explicit note.

- **Benefits versus Impacts:** In presenting the approach and results of our analysis, we distinguish between potential societal *benefits* of RPS programs (GHG, air pollution, and water use reductions) and other *impacts* of those programs (gross jobs and economic development and natural gas price reductions). In evaluating potential benefits, we consider both beneficial and detrimental effects from RPS resources—the latter including, for example, air pollutants emitted by biomass and water use by concentrating solar power facilities. The impacts that we evaluate are sometimes described as benefits, and in some cases may be benefits from the perspective of an individual state or entity. However, at a national or global scale, the impacts of RPS programs related to gross jobs and economic development and to natural gas price suppression are best considered resource *transfers*: benefits for some stakeholders at the expense of others. For these impact categories, we do not evaluate the *net* effects over the entire economy and, as such, cannot assess whether or not these impacts reflect net costs or benefits. Net impacts between stakeholders are possible, but our assessment does not determine the magnitude or direction of such net effects. Such impacts may still be relevant to evaluating state RPS programs, especially by state policymakers. However, it is important to acknowledge any offsetting effects that may take place at the sectoral, regional, national, or even international scales.

- **Scope of Costs, Benefits, and Impacts:** Our analysis considers an important subset of—but not all—potential costs, benefits, and other impacts. For example, we do address integration of utility-scale RE into the transmission grid within the capabilities of our electric sector models but do not assess the challenges of integrating RE into distribution grids or the full set of impacts on economic development or energy supply risks. We also do not quantify the land use impacts from the RE deployment serving state RPS policies nor the offsetting reduction in impacts from fossil fuel energy supplies. Other non-quantified environmental impacts include heavy metal releases, radiological releases, waste products, and water quality impacts associated with power and upstream fuel production, as well as wildlife, noise, aesthetics, and others.
- **Cost-Effectiveness:** RPS programs are not the only possible way to achieve the outcomes discussed in this paper. Rather, as widely recognized in the economics literature, "internalizing externalities" is generally most cost-effectively achieved by directly pricing those externalities rather than through technology- or sector-specific policies. This is partly due to possible economy-wide rebound, spillover, or leakage effects, and also because such policies more directly target the achievement of public benefits (Borenstein 2012; Edenhofer et al. 2013; IPCC 2011; IPCC 2014; Kalkuhl et al. 2013; McKibbin et al. 2014; Tuladhar et al. 2014). Research focused on RPS policies has highlighted these possible effects, finding that the desired benefits of RPS programs may not be fully achieved or achieved as cost effectively as might be desired (Bushnell et al. 2007; Carley 2011; Fischer and Newell 2008; Fell and Linn 2013; Rausch and Karplus 2014), though other research suggests that the pitfalls of such "second-best" policies may be modest (Kalkuhl et al. 2012).
- **Additionality:** Our analysis estimates the costs, benefits, and other impacts associated with RE used to meet RPS demand growth going forward, but it does not seek to *attribute* those effects solely to RPS policies. Because of the potential leakage and spillover effects noted above, and also because of the multiple drivers for RE additions—of which state RPS programs are but one—the estimates presented in this paper may overstate the effects (including both costs and benefits) solely attributable to state RPS programs. Previous research, for example, has come to mixed conclusions about the incremental effect of RPS programs on RE deployment (Carley 2009; Carley and Miller 2012; Menz and Vachon 2006; Sarzynski et al. 2012; Shrimali et al. 2015; Shrimali and Jenner 2013; Shrimali and Kniefel 2011; Staid and Guikema 2013; Yin and Powers 2010).
- **Uncertainty:** Considerable uncertainty underlies many elements of our analysis. Where possible, we quantify the range of possible outcomes. In other cases, we qualify the study results and highlight areas of uncertainty not explicitly addressed in the analysis.

Roadmap

The remainder of this paper is structured as follows. Section 2 describes the methods used to model dispatch and capacity expansion of the U.S. electric generation fleet under each scenario and to estimate each of the benefits and impacts covered in this report. Section 3 presents modeled shifts in renewable generation and displacement of fossil fuel generation under each scenario, while Section 4 describes the modeled costs of the RPS scenarios, both in terms of total system costs and average electricity prices relative to the baseline scenario. Sections 5 and 6 then present estimates for each of the potential benefits and impacts in turn: GHG emissions, air pollution emissions, water use, development of jobs, economic development, and natural gas price suppression. We conclude in Section 7 with a summary of our findings and their implications.

2. Methods: Electric Sector Modeling and Impact Assessment Methods

Overview

This analysis is built on a suite of analytical tools and methods, depicted in Figure 2.1. These tools closely follow a number of reports conducted for and by the DOE (DOE 2015; DOE 2016; Wiser et al. 2016b), including our 2016 study evaluating the historical benefits and impacts of existing RPS programs (Wiser et al. 2016a).

The ReEDS electricity capacity expansion model forms the core of the analysis and is used to estimate renewable and non-renewable capacity and generation through 2050 under each scenario and sensitivity case. The dSolar customer adoption model provides inputs to ReEDS for rooftop photovoltaic capacity additions (Sigrin et al. 2015). In addition to estimating generation and capacity by fuel type, ReEDS also directly computes total electric system costs, air pollutant (nitrogen oxides [NO_x] and sulfur dioxide [SO_2]) emissions, life-cycle GHG emissions, water consumption and withdrawals, and changes in regional natural gas prices associated with natural gas consumption by electric power generation. Each of those outputs is then used to estimate individual benefits and impacts, in many cases requiring additional analytical tools and computations outside of ReEDS. Each of these steps is described in detail throughout the remainder of this section.

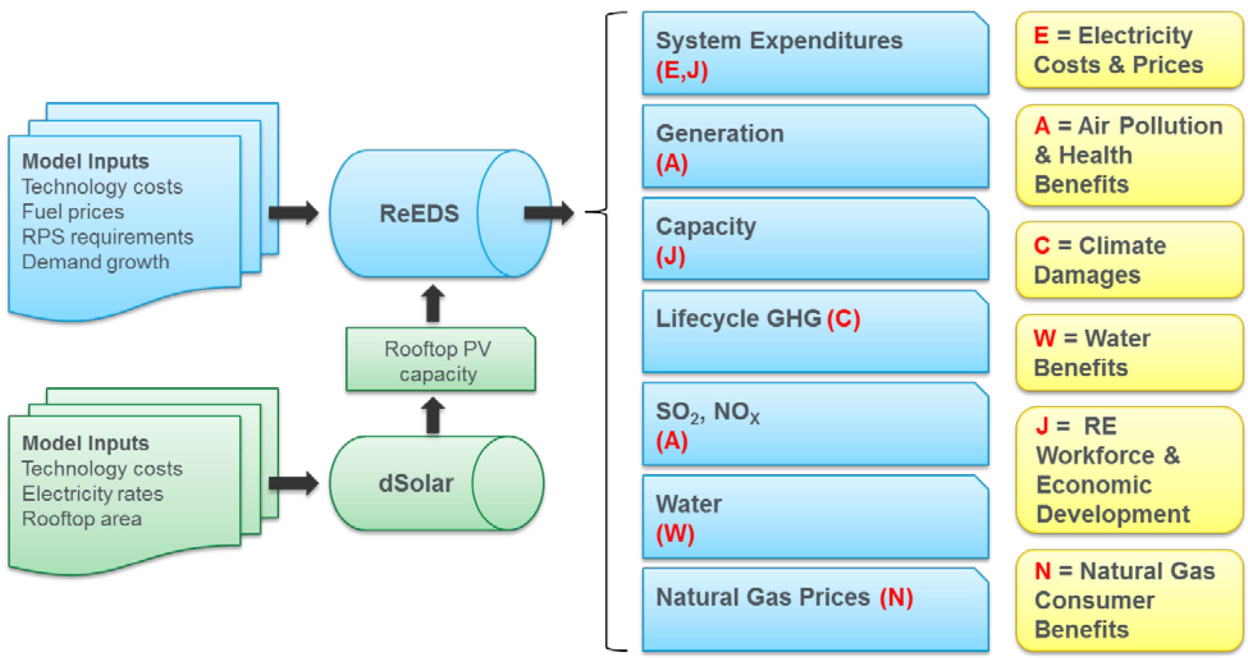


Figure 2.1. Modeling and data analysis to support cost, benefit, and impact estimates

Note: Red letters in parentheses indicate in which benefit/impact analyses each data set was used.

Electricity Sector Modeling and Scenario Definitions

The ReEDS model is the core analytic backbone of our analysis (Short et al. 2011; Eurek et al. 2016).[5] It is a capacity expansion model used to develop future scenarios of the electricity system in the contiguous United States. Specifically, ReEDS relies on an optimization approach to determine new capacity of multiple renewable and non-renewable technologies, and the generation from new and existing power plants, from the present to 2050 while meeting electricity consumption, other grid services, and policy requirements. ReEDS is designed to address the unique characteristics of many renewable electricity technologies, particularly the variability and uncertainty of solar and wind resources and the location-dependence of RE resources. The model accomplishes this through high spatial resolution and statistical parameterizations (Short et al. 2011) to estimate renewable capacity value, curtailment, and operating forecast error reserve requirements that inform model investment and dispatch decisions. ReEDS considers transmission expansion, which is needed to compare, for example, the cost competitiveness of remote high-quality renewable resources versus lower-quality local resources. The high spatial resolution in the model is also used to reflect regional differences in policies and to self-consistently project national and state policy compliance mechanisms under different future conditions.

In this study, we use ReEDS to simulate three scenarios of the U.S. electricity system through 2050, each of which is described further in the remainder of this section:

- **No RPS:** A counterfactual scenario that assumes no further growth in RPS requirements beyond 2014 and that economic growth in RE is capped at the same level as in the Existing RPS scenario
- **Existing RPS:** Based on existing state RPS policies as of July 2016
- **High RE:** A hypothetical scenario in which all states adopt expanded RPS targets.

For each scenario, the primary ReEDS outputs are annual generation and installed capacity by technology type from 2014 to 2050. From those outputs, the various costs, benefits, and other impacts reported within this study are estimated. Costs are estimated directly within ReEDS, while benefits and other impacts are often estimated using additional analytical techniques that rely directly on ReEDS outputs, as described throughout the remainder of this section. Incremental impacts are calculated by comparing the Existing and High RE Scenarios to the No RPS scenario.

Key Input Assumptions

The core assumptions used in the electric sector modeling in this study are consistent with those from NREL's *2016 Standard Scenarios* report (Cole et al. 2016). In particular, we rely on demand growth and fossil fuel prices from the *EIA Annual Energy Outlook 2016* Reference Case (EIA 2016) and renewable and non-renewable technology cost and performance assumptions based on the NREL Annual Technology Baseline 2016 "mid" projections.[6] In these projections, levelized costs for land-based wind energy are estimated to decline from 2014 levels by 16% by 2030 and 21% by 2050. The unsubsidized levelized costs of energy for utility photovoltaics are estimated to decline from 2014 levels by as much as 68% by 2050. Other generation technologies are also estimated to experience cost declines of varying levels as reported in the Annual Technology Baseline 2016 data. Storage and transmission costs are based

[5] ReEDS has been widely used in previous analysis of long-term renewable futures (DOE 2015, 2016; Wiser et al. 2016a; NREL 2012) and to simulate scenarios for analyses of a broad range of state and federal energy policies and regulations (Mai et al. 2016; Cole et al. 2015; Lantz et al. 2014; Mignone et al. 2012; Bird et al. 2011; Logan et al. 2009).We use the 2016 Final Release version of ReEDS in our analysis. Additional information about ReEDS can be found on the model website: http://www.nrel.gov/analysis/reeds/.

[6] http://www.nrel.gov/analysis/data_tech_baseline.html

on the same assumptions from the NREL 2016 Standard Scenarios report (Cole et al. 2016; Eurek et al. 2016). All three model scenarios—No RPS, Existing RPS, and High RE—rely on the same set of assumptions.[7]

Recognizing the uncertainties in future technology costs and fuel prices, we also model four additional sets of sensitivities that include high and low assumptions for natural gas prices and renewable technology costs. The natural gas price scenarios are based on the *Annual Energy Outlook 2016* High and Low Oil & Gas Resource cases (EIA 2016), and the renewable technology sensitivities are based on the Annual Technology Baseline 2016 High and Low RE cost projections. For all sensitivities, only one set of parameters was varied at a time, and all other assumptions were kept consistent with the primary scenario. The full set of three scenarios (Existing RPS, High RE, and No RPS) was modeled across the natural gas price and renewable cost scenarios, and the results were used to estimate a range in costs. The various benefit and impact categories were evaluated using only the central-case assumptions for fuel prices and RE technology costs, although the cost categories are presented as a range based on the results from the full set of natural gas and RE price sensitivities. Uncertainties in many of those benefit and impact categories were also estimated but were based on other underlying sources of uncertainties.

Existing RPS Scenario

The Existing RPS scenario is based on all existing state RPS policies, as of July 2016.[8] We model primary RPS requirements as well as technology-specific carve-outs and account for state-specific technology eligibility requirements. RPS demand projections developed by Lawrence Berkeley National Laboratory are used to inform the modeled RPS requirements, resource eligibility, and technology carve-outs.[9] The Lawrence Berkeley National Laboratory RPS demand projections are converted to a percent of electricity sales in ReEDS, to ensure consistency with the ReEDS electricity consumption growth and behind-the-meter distributed generation projections.

[7] We do not model technology learning in ReEDS. In addition, although base assumptions around fuel resource supply are consistent across all scenarios, ReEDS includes supply curves to reflect the price elasticity of power sector natural gas consumption. As a result, the output gas prices differ between scenarios, and these differences are used in our assessment of impacts to natural gas consumers and producers.

[8] The scenario includes recent revisions to state RPS policies in Oregon, Rhode Island, Vermont, and the District of Columbia. ReEDS does not have a region specifically for the District of Columbia, but includes any electricity demand, generation, or policies in the District of Columbia in the Maryland region. Importantly, the scenario does not include the New York clean energy standard passed in August 2016 or any other policies enacted since then because the model scenarios were complete by the time the policies were announced. Unless otherwise noted by the policy, we maintain the same RPS requirement (in percent terms) for all years after the terminal year of the policy. Model representation of existing RPS policies can be found in the appendix of Frew et al. (2016) and Eurek et al. (2016).

[9] Some analyst judgment was needed to represent resource eligibility, particularly for existing and new hydropower resources and for qualifying biomass facilities. Judgments were also applied when modeling in-state requirements and incentives. In addition to primary-tier RPS requirements, we also model three technology-specific carve-outs for wind, solar, and distributed generation. For the latter two carve-outs, we assume for each state whether or not the carve-out is met by utility-scale or distributed solar based on policy requirements or, when no clear specification is available, historical practices. Finally, we reviewed existing (2015) RE capacity to assess whether it was contractually available to meet future RPS compliance. This assessment resulted in an estimate of about 40 terawatt-hours (TWh) (out of about 160 TWh excess RE generation beyond RPS requirements) of 2015 RE generation in the existing fleet available for future RPS obligations. These 40 TWh are not deducted in the No RPS scenario and therefore we do not fully capture the impacts of these potentially “banked” renewable energy certificates. They do, however, help to reduce compliance costs as they lower the need for investments in new (post-2014) RE capacity to meet growing RPS requirements. See Barbose (2016a) and http://rps.lbl.gov for further details on the RPS data used in the ReEDS modeling.

RPS policies are represented in ReEDS in terms of constraints requiring a minimum number of renewable energy credits (RECs) from RPS-eligible technologies to be retired in each year for load served in RPS states. We allow interstate REC trading based on legislated eligibility rules and historical practices (Holt 2016; Heeter et al. 2015).[10] We also allow states to satisfy compliance obligations via alternative compliance payment mechanisms rather than by retiring RECs, where applicable.[11] Further details on ReEDS' representation of RPS policies are described in Frew et al. (2016) and in the latest ReEDS documentation (Eurek et al. 2016).

Also important to note is that RE generation is allowed to exceed RPS requirements, thus some additional "economic RE" is generated. Economic RE is assessed within the least-cost framework of the ReEDS model based on the assumed costs of all generation technologies, including interconnection, transmission, and other factors, as well as the relative value of the different modeled options to the system. That incremental economic RE generation, above and beyond what is needed to meet RPS demand growth, is used as a constraint on RE growth in the No RPS scenario, as described below. Finally, other major existing policies are modeled in this scenario, including federal RE tax credits and state and regional carbon policies. The one major exception is the Clean Power Plan (CPP), which is used as the point of reference for constructing the High RE scenario and is excluded from the Existing RPS scenario.

High RE Scenario

This scenario represents a hypothetical future in which all states choose to adopt relatively aggressive RPS policies and is intended to help inform efforts by states who may be considering new or expanded RPS targets. As a proxy for what this might entail, RE targets under this scenario are based on the level of RE growth that would occur if states were to meet the entirety of their CPP compliance obligations solely with RE generation.[12,13] This is implemented in ReEDS by limiting annual natural gas-fired generation to the amounts in the Existing RPS scenario.[14] To be clear, this scenario specification is not intended to suggest that such a strategy will be least-cost nor does it presuppose that the CPP will be implemented. However, given that the CPP has been a common consideration among stakeholders in recent discussions about new or revised RPS policies, it provides a useful point of reference. Also important to note is that this scenario does not represent any particular economic or technical upper limit on RE.

No RPS Scenario

This scenario serves as the counterfactual baseline from which the costs, benefits, and other impacts in the Existing RE and High RE scenarios are measured. This scenario holds RPS requirements constant after

[10] Restricting REC trading based on historical practices may be overly stringent on future REC trading. The model REC trading representation and trading limits are applied to ensure that RECs are only retired once and to avoid REC trading between states that are not allowed by legislation.

[11] The model treats all RPS states as though alternative compliance payment mechanisms are available. However, for states that, in fact, do not allow alternative compliance payments, we assume arbitrarily high alternative compliance payment levels ($200/megawatt-hour (MWh) for primary-tier RPS requirements and $400/MWh values for carve-out requirements) in order to ensure that the modeled RPS requirements are met with RECs.

[12] The CPP regulations allow states various options for compliance, including state measures plans, which could include RPS policies that are "federally enforceable" and can be used to comply with the CPP.

[13] We model this scenario as though the CPP were implemented with "mass-based" emission targets for each state, with no allowance trading between states.

[14] By restricting coal-to-gas fuel switching beyond that found in the Existing RPS scenario, this implementation forces the model to reduce generation from CO_2-emitting plants. Because ReEDS does not have other endogenous mechanisms to reduce emissions (e.g., heat rate upgrades or energy efficiency), it deploys greater amounts of renewable energy to replace the reduced generation.

2014 (also reducing the amount of exogenously specified rooftop photovoltaics associated with solar and distributed generation RPS carve-outs).

Aside from removing RPS requirements, the other key feature of the No RPS scenario is that economic RE growth is allowed to take place, but is capped at the level of economic RE in the Existing RPS scenario. The rationale for this approach is to be able to assess the effects of all RE used to meet RPS demand growth and to provide a baseline for assessing system costs. To implement the cap on economic RE growth, we apply an upper limit on annual RE generation for each individual census region.[15] Specifically, the limit is equal to the difference between annual RE generation and annual RPS requirements in the Existing RPS scenario.[16] The cap is applied at the census division level rather than the state level to account for interstate REC transactions and electricity transmission.[17]

Similar to the Existing RPS scenario, the No RPS scenario also excludes the CPP but includes all other existing state and federal policies. However, the stringency of state and regional carbon policies (in particular, the Regional Greenhouse Gas Initiative (RGGI) and California's cap-and-trade program) was reduced in the No RPS scenario. New RE is one mechanism used to comply with those state and regional carbon policies; however, because we are restricting RE generation in the No RPS scenario, the stringency of the carbon emissions requirements was reduced as to not exaggerate costs in this scenario.[18]

Metrics to Estimate Electric System and Consumer Costs

Two cost metrics are calculated in ReEDS and reported in this study. The first is the net present value of system costs, which includes all electric system expenditures through the study horizon (2015–2050). The expenditures include all fixed and operating costs, including capital costs for all renewable, non-renewable, and supporting (e.g., transmission and storage) electric sector infrastructure; fossil fuel, uranium, and biomass fuel; and plant operations and maintenance (O&M). Future costs are discounted

[15] The scenarios are constructed as follows: First, the Existing RPS scenario, which allows for RE generation in exceedance of RPS requirements, is modeled. Then, for each census region and year we evaluate the difference between RE generation in this scenario and the aggregate RPS requirement in the region. This difference is then used to construct a constraint that caps RE generation for the No RPS scenario. (We also reduce rooftop PV generation according to any regional solar or distributed generation carve-outs.) Finally, using the new caps, we simulate the No RPS scenario. As a result, differences in RE generation between the Existing RPS and No RPS scenarios reflect the RPS requirements.

[16] This scenario construct implicitly associates the more-expensive RE generation to the RPS required share because the cap on RE generation in the No RPS scenario would result in lower-cost RE to be deployed first in that scenario.

[17] RPS compliance can often be met by out-of-state resources and can impact the dispatch of out-of-state generators. We acknowledge that census division boundaries do not align perfectly with REC and electricity markets, but implementing the caps at the census region level captures these regional effects to some degree. This regional representation also helps to mitigate the inability of ReEDS to track REC banking.

[18] We apply an iterative process to estimate the revised carbon cap levels. This process required running the No RPS scenario without any deviations from the carbon caps in California and the RGGI states. We estimate the carbon intensity of incremental RE—defined as the different in RE generation in the Existing RPS and No RPS scenarios—by using the ratio of the incremental RE generation to avoided CO_2 emissions. These carbon intensities are estimated for in-state/in-region generation and imported generation. The carbon caps are then adjusted by these estimated carbon intensities and the amount of incremental generation. The ReEDS documentation (Eurek et al. 2016) describes the standard representations of RGGI and the California cap-and-trade programs.

using a 3% (real) social discount rate.[19] In addition, due to the long lifetimes of electric system infrastructure, we only include fractions of the capital expenditures that are incurred by 2050. The ReEDS documentation (Eurek et al. 2016; Short et al. 2011) explains this apportionment in detail.[20] Although the production and investment tax credits are included in the model decision-making, they are not included when estimating the net present value of system costs because these RE tax credits reflect a transfer of costs between taxpayers and the electricity system. Including the tax credits in this metric would lower the estimated values from what are otherwise presented here.

The second cost metric reported is the retail electricity price. For this study, electricity prices are based on the marginal values of key restrictions used in the model, including load balancing, operating reserves, planning reserves, and policy constraints.[21] These prices are akin to hourly locational marginal prices used by system operators for electricity market clearing, but the prices output by ReEDS are averages over all hours of the year and include capacity prices and ancillary service prices. Thus, they implicitly cover both fixed and variable costs for all generators. Although competitive pricing is not ubiquitous in all U.S. regions, a majority of electricity sales occur in restructured markets, thus these modeled prices are a useful metric for estimating relative costs incurred by the bulk power system.[22] ReEDS does not model the distribution system—including any needed upgrades or maintenance—and we do not make any assumptions or estimates for how distribution system costs might evolve across scenarios. ReEDS also does not estimate retail mark-ups. We therefore assume that differences in ReEDS-estimated electricity prices are passed through directly to retail electricity prices.

As with any model, ReEDS requires many simplifications. These simplifications can impact all model results, but can have particularly significant impacts on estimated costs. We note some of the key limitations and caveats of ReEDS with respect to estimated scenario costs below:

- **System-wide optimization.** The model decision-making seeks to optimize system-wide costs for the contiguous United States as a whole. Actual decision making in utility and transmission planning, procurement, and dispatch processes may not be optimized. As such, costs in all scenarios will likely be higher than those estimated by ReEDS.[23] Although this likely impacts all scenarios, it is probable that this underestimation of costs in ReEDS is more prominent for scenarios with higher RE shares due to the location-restricted and variable nature of many renewable resources. Furthermore, ReEDS does not model non-economic decisions, which might lead to higher actual costs than those reported.
- **Siting and supply chain.** ReEDS does not explicitly model siting and supply chain constraints. Again, because these factors might impact RE to a greater degree than other generation technologies,

[19] The use of a social discount rate in our system cost metric is consistent with discount rates used by the EIA, the International Energy Agency, and the Intergovernmental Panel on Climate Change to estimate long-term costs and benefits. A 3% discount rate is also in line with guidance from the White House Office of Management and Budget for "cost-effectiveness" analysis that spans multiple decades. Note that this discount rate differs from the higher discount rate (5.3% real, weighted average cost of capital) used in most cases for the ReEDS investment and dispatch decision-making.

[20] ReEDS uses a 20-year economic lifetime for all generation technologies. As such, only a fraction of the 20-year net present value costs of new capital equipment installed after 2030 are included in the system cost metric.

[21] Endogenously- estimated REC prices are rolled into the competitive electricity price.

[22] ReEDS also includes a cost-of-service price (Eurek et al. 2016) that is more reflective of pricing in regions without restructured markets. For this study, we report competitive prices only but note that the estimated incremental cost-of-service prices are similar in magnitude.

[23] However, reported costs from ReEDS for a particular region might be either higher or lower than real costs under the same set of scenarios. For example, a region might find lower cost solutions for it than the system-wide minimum cost solution.

their lack of representation might skew the reported incremental costs of scenarios with higher amount of RE to be lower than they might otherwise be.

- **Foresight.** Only limited foresight is modeled in ReEDS.[24] It is not clear how real investor foresight compares with that modeled in ReEDS. And while accurate foresight may yield lower costs in all scenarios, it is not clear how better foresight might impact cost differences across scenarios.

METHODS FOR ASSESSING BENEFITS AND IMPACTS

Evaluating the Benefits and Impacts of State RPS and High RE Scenarios

In addition to analyzing the possible costs associated with the Existing RPS and High RE scenario, we evaluate a diverse set of possible benefits and impacts. We report results in physical units and—where credible methods exist—in monetary terms. We evaluate the Existing RPS and High RE scenarios relative to the No RPS scenario to identify the full set of benefits and impacts of all additional RE demand associated with those scenarios. We report results for the full analysis timeframe of 2015–2050, in some cases also highlighting nearer-term results to 2030.

Various aspects of our methods to estimate GHG and air pollution benefits build on or complement approaches used by U.S. regulatory agencies (GAO 2014; EPA 2015c) and academic researchers (NRC 2010; Arent et al. 2014; Buonocore et al. 2016a; Buonocore et al. 2016b; Callaway et al. 2015; Chiang et al. 2016; Cullen 2013; Graff Zivin et al. 2014; Driscoll et al. 2015; Fann et al. 2012; Johnson et al. 2013; Kaffine et al. 2013; McCubbin and Sovacool 2013; Novan 2014; Rouhani et al. 2016; Siler-Evans et al. 2013; Shindell 2015). The basic approach used for estimating water use impacts has also been applied in multiple studies (Clemmer et al. 2013; Macknick et al. 2012; Macknick et al. 2015; Rogers et al. 2013). The same is true for our assessments of gross RE-workforce and economic development impacts (Bamufleh et al. 2013; Croucher 2012; Flores et al. 2014; Keyser et al. 2014; Lantz and Tegen 2008; Loomis and Carter 2011; Navigant 2013; Slattery et al. 2011; Steinberg et al. 2012; You et al. 2012), and natural gas price impacts (Fischer 2009; Wiser and Bolinger 2007).

Air Pollutant Emissions and Human Health and Environmental Benefits

Our methods to value the potential air quality benefits of the Existing RPS and High RE scenarios involve first estimating the net reductions in direct combustion-related emissions of SO_2, NO_x, and fine inhalable particles with diameters that are generally 2.5 micrometers and smaller ($PM_{2.5}$) relative to the No RPS scenario. We then quantify the public health and environmental benefits of those changes in emissions in the form of reduced mortality and morbidity associated with exposure to particulate matter and ground-level ozone, and translate those effects into monetary terms.[25]

Combustion-related electric-sector emissions of SO_2 and NO_x are estimated within ReEDS using emission rates developed based on recent measurements of power plant emissions (Ventyx 2013) and adjusted over time to reflect EPA's Mercury Air Toxics Standard. Combustion-related $PM_{2.5}$ emission estimates are less certain and estimated outside of ReEDS as the product of ReEDS generation outputs (megawatt-hours, by generation type and vintage) and average emission rates (grams per megawatt-hour, by generation type

[24] ReEDS includes imperfect foresight related to changing natural gas fuel prices. The foresight term includes a expectation of changing natural gas fuel prices based on data from the 2016 Annual Energy Outlook scenarios (EIA 2016), but since ReEDS includes an endogenous representation of power sector natural gas price and demand dynamics, future prices observed in the model ultimately differ from these projections.

[25] These represent a subset—but arguably the most important—of emissions impacts. Due to methodological and data limitations, we do not evaluate impacts from heavy metal releases, radiological releases, waste products, and land use impacts associated with power and upstream fuel production as well as noise, aesthetics, and others. Note also that we only consider SO_2, NO_x, and $PM_{2.5}$ emissions from power plant operation, and so do not assess upstream and downstream life-cycle impacts.

and state).[26] Biomass emissions are also estimated outside of ReEDS and are more uncertain than emissions from fossil fuel units. Specifically, biomass emissions rates of SO_2 and $PM_{2.5}$ are based on the national average values developed in Wiser et al. (2016b). The NO_x emission rates are newly updated with EIA data (EIA 2015).[27] Overall, our methodology presumes that the Mercury Air Toxics Standard is maintained or replaced with a similar regulation so that SO_2 and NO_x cap-and-trade programs, such as the Cross-State Air Pollution Rule (which is also modeled in ReEDS), are essentially non-binding over time.[28] If emissions regulations become more stringent than assumed in our analysis or if binding cap-and-trade programs are created, then the resulting impacts of the Existing RPS and High RE scenarios would differ from those shown here.

The marginal impacts of air pollutant emissions on health outcomes (including morbidity and mortality outcomes and total monetary value) are an area of active research, and we reflect some of this uncertainty by calculating benefits using three distinct methods. All three approaches include representation of pollutant transport and chemical transformation to assess population exposure and response. Each does so differently, however, and considers different health and environmental outcomes. We use: (a) the Air Pollution Emission Experiments and Policy analysis model (AP2, formerly APEEP; described in Muller et al. 2011)[29]; (b) EPA's marginal benefit methodology (EPA 2015a; EPA 2015c)[30]; and (c) The Estimating Air pollution Social Impacts Using Regression (EASIUR) model (Heo et al. 2016).[31]

To incorporate differences across epidemiological studies, EPA and EASIUR both include two estimates of health impacts, a low estimate and a high estimate. Moreover, the EPA methods allow us to estimate specific health outcomes (mortality and specific forms of morbidity); all methods allow for monetary quantification. We report a "central" value estimate as the simple average of all other estimates.[32]

[26] Average $PM_{2.5}$ emissions rates (Cai et al. 2012; Cai et al. 2013) are differentiated by generation type (coal, gas, or oil) and U.S. state, and are adjusted over time to comply with scheduled $PM_{2.5}$ limits in the Mercury Air Toxics Standard for existing plants.

[27] Although EIA data for biomass were incomplete for $PM_{2.5}$ and SO_2, we were able to derive and use state-level estimates of NO_x emission rates. These state-level estimates produced an average national NO_x emission rate for biomass that was within 20% of the NO_x emission rate in Wiser et al (2016b).

[28] Otherwise, emissions impacts should arguably be valued at allowance prices to reflect savings in the cost of complying with the cap (Siler-Evans et al. 2013). Note that we do not include some more-localized existing binding cap-and-trade programs. The geographic extent of these programs is limited, so they will not substantially bias our results.

[29] AP2 contains monetized benefit-per-ton estimates based on emissions in the year 2008, so damages from AP2 are scaled over time based on Census population projections (U.S. Census Bureau 2012) and per capita income growth projections used by EIA (2014), using an elasticity of the value of statistical life to income growth consistent with National Research Council (2010).

[30] EPA's benefit-per-ton values are developed for each year within each of three large regions by linearly extrapolating EPA's provided benefit-per-ton values. The 2015–2025 benefit-per-ton values are based on the linear trend established by EPA's 2020 and 2025 values. The 2026–2050 benefit-per-ton values are based on the linear trend established by EPA's 2025 and 2030 values. The same process is used for EPA's health incidence-per-ton (mortality and morbidity outcomes) estimates.

[31] EASIUR contains monetized benefit-per-ton estimates based on population and income in the year 2005, so damages from EASIUR are scaled over time based on Census population projections (U.S. Census Bureau 2012) and per capita income growth projections used by EIA (2014), using an elasticity of the Value of Statistical Life (VSL) to income growth consistent with National Research Council (2010).

[32] A critical value within each approach is the monetary value of preventing a premature mortality (or the VSL). Each approach is based on a VSL of approximately $6 million (in 2000$), which is consistent with the broader literature.

Greenhouse Gas Emissions Reduction Benefits

We estimate the potential life-cycle GHG benefits of the Existing RPS and High RE scenarios, relative to the No RPS scenario, by quantifying the economic value of those GHG reductions in mitigating the severity of climate-related damages and in meeting potential future carbon-reduction compliance obligations.

ReEDS calculates operational combustion-related CO_2 emissions that result from electric sector dispatch.[33] Additionally, based on the comprehensive literature assessment conducted under the auspices of NREL's Life Cycle Assessment Harmonization project,[34] embedded within and calculated by ReEDS are assumptions that enable an evaluation of the full life-cycle GHG impacts associated with: (1) ongoing fuel-cycle emissions from the production and transport of fuels and from other aspects of power plant operations, (2) construction-related emissions, and (3) emissions from end-of-life decommissioning.[35] By applying these life-cycle adjustments, we capture avoided fuel cycle, construction, and decommissioning emissions from displaced fossil generation and capacity while also accounting for increased fuel cycle, construction, and decommissioning emissions from renewable generation and capacity.

We estimate the monetary benefits of reduced climate-change damages from GHG reductions using social cost of carbon (SCC) estimates. The SCC provides an estimate of climate change-induced monetary damages to agricultural productivity, human health, property, ecosystem services, and other systems, presented below in units of \$/(metric ton CO_2). There is a wide range of SCC estimates in the scientific literature, illustrating the deep uncertainties involved. SCC estimates are particularly sensitive to the choice of discount rates, estimates of future climate change damage and the potential for catastrophic climate tipping points, as well as the representation of abatement policies (Nordhaus 2014). Meta-analyses (Tol 2008; Tol 2011; Tol 2013) of independent SCC estimates have been conducted, with the most recent work (Tol 2013) finding mean and median SCC values of \$53 and \$37, respectively, and an associated standard deviation of \$88. Tol (2013) developed these values based on 75 studies containing 588 estimates of the SCC. Havranek et al. (2015) build on the work by Tol (2013) and attempt to correct for selective reporting bias, finding a mean SCC estimate between \$0 and \$39. Still others, such as van den Bergh and Botzen (2014), argue for a *lower bound* SCC value of \$125.

[33] We do not consider the possible erosion of the GHG or air emissions benefits due to the increased cycling, ramping, and part loading required of fossil fueled generators in electric systems with higher penetrations of variable renewable generation, as these impacts are not fully considered in ReEDS. This omission will not meaningfully bias our results, however, because the available literature demonstrates that these impacts are generally relatively small (Fripp 2011; Göransson and Johnsson 2009; Gross et al. 2006; Pehnt et al. 2008; Perez-Arriaga and Batlle 2012; Oates and Jaramillo 2013; Valentino et al. 2012; GE Energy Consulting 2014; Lew et al. 2013).

[34] See http://www.nrel.gov/harmonization.

[35] Specifically, median life-cycle, non-combustion GHG emission values were identified for each generation technology and for the fuel cycle, construction, and decommissioning phases based on the NREL's Life Cycle Assessment Harmonization project literature assessment. We use the same emission factors as those employed in the Hydropower Vision study (DOE 2016, Appendix G). To estimate non-combustion GHG emissions from the fuel cycle, we use the electricity-production estimates (in) provided by ReEDS for all generation technologies and apply the median, literature-derived estimates of technology-specific, non-combustion fuel-cycle GHG emissions. There is uncertainty in these estimates (Brandt et al. 2014, Arent et al. 2015). We assume that biomass GHG combustion emissions are entirely offset by carbon absorption to produce the biomass feedstocks (i.e., we do not estimate land-use related emissions), and that any landfill gas used for electric production would otherwise have been flared. To estimate GHG emissions from construction, we use the capacity estimates (in megawatts) provided by ReEDS over the 2015 to 2050 timeframe and apply the median, literature-derived estimates of technology-specific, construction-related GHG emissions. Finally, to estimate GHG emissions from decommissioning, we use decommissioning capacity estimates (in megawatts) provided by ReEDS over the 2015 to 2050 timeframe and apply the median, literature-derived estimates of technology-specific, decommissioning-related GHG emissions.

U.S. government regulatory bodies use estimates for the SCC that were determined by the U.S. Interagency Working Group (IWG) on the Social Cost of Greenhouse Gas Emissions (IWG 2010; IWG 2015) when formulating policy (GAO 2014; Kopp and Mignone 2012).[36] The SCC estimates from the IWG represent global future damages from GHG emitted in a particular year, with the future damages calculated in present value terms using a selected range of discount rates. To address the range of assumptions that can be used to formulate the SCC, the IWG provides four different SCC estimates (e.g. for 2010: $11, $33, $53, and $90, with the value of $33 described as the central estimate). Thus, the IWG SCC estimates cover a similar range to that found in the meta-analyses described above.

As an alternative to valuing GHG reductions based on the SCC, we also value those reductions based on the possible cost of complying with legal requirements to reduce GHG emissions. The EPA may limit GHG emissions from existing and new power plants through the CPP (EPA 2015a; EPA 2015b; Luckow et al. 2016), though the legal fate of the CPP is unclear. When binding cap-and-trade programs are used to limit GHG emissions, the climate-change benefits of RE might best be valued based on the cost of complying with those legal requirements (Barbose et al. 2008; Cullen 2013; Siler-Evans et al. 2013). In this case, the GHG benefits of RE come in the form of helping to meet the carbon-reduction target and thereby offsetting some of the "marginal" costs of complying with the policy.

Specifically, we value the potential compliance-cost savings of GHG reductions based on two sets of estimates. First, we use EPA estimates of the average national cost of complying with the CPP under both mass-based and rate-base application (EPA 2015a).[37] Those estimates are provided by EPA for 2020, 2025, and 2030; we interpolate between these years to estimate costs in intervening periods and further assume the 2030 compliance cost estimates remain constant through 2050. Second, we use Synapse Energy Economics projections of carbon costs under "low," "medium," and "high" trajectories (Luckow et al. 2016). Synapse considers the possibility of more stringent long-term carbon-reduction goals than envisioned by the CPP and so estimates higher costs than those from EPA (2015a).[38]

Water Use Reduction Benefits

Electric sector water usage comes in two forms. *Withdrawal* is defined as water removed from and then returned to a source. *Consumption* is defined as water that is removed from but not returned to its source. Withdrawals include cooling water returned to its source at a higher temperature; consumption includes water evaporated for cooling. We estimate the impacts of the Existing RPS and High RE scenarios on both withdrawals and consumption relative to the No RPS scenario and present results based on the 18 U.S. Geological Survey Hydrologic Unit Code watershed regions (Seaber et al. 1987).

Electric sector water withdrawal and consumption were estimated within ReEDS for all generation types. ReEDS includes representations of cost, performance, and water-use characteristics by generation type and cooling system technology, and new power plant construction is limited by water availability

[36] The Technical Support Document "Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866," describes recent updates to the IWG work, including additional discussion of uncertainty.

[37] While EPA has also estimated state-level marginal carbon-abatement costs, we prefer to use national average estimates because of the uncertainty introduced at the state- level due to the flexibility allowed in a state achieving the CPP. Also, average cost estimates may be more appropriate than marginal estimates as the carbon reductions associated with the two core scenarios analyzed for this report represent either a sizable contribution to CPP compliance (Existing RPS scenario) or reflect full compliance with the CPP (High RE scenario).

[38] Note that we apply the IWG SCC estimates to the estimated life-cycle GHG emissions savings (in CO_2-equivalent) whereas we apply compliance cost estimates only to combustion-related electric-sector emissions (only CO_2) because EPA CPP regulations, if enacted, would apply only to the electric sector.

(Macknick et al. 2015). ReEDS incorporates a representation of cooling systems for the existing generation fleet based on an analysis of individual power-generating units as described elsewhere (Averyt et al. 2013; UCS 2012). Various changes in the electricity sector, such as coal plant retirements, new combined-cycle natural gas plant construction, and increased dry cooling use, can impact water use. These changes, in turn, may be driven in part by future water policies, which could affect estimated water impacts. Following Macknick et al. (2012) and Tidwell et al. (2013), new power plants modeled in ReEDS do not have the option of installing once-through cooling technologies.

We focus exclusively on operational water-use requirements because thermoelectric water withdrawals and consumption during plant operations are orders of magnitude greater than the demands from other life-cycle stages (Meldrum et al. 2013). Thermal power plants using once-through cooling withdraw far more water for every megawatt-hour of electricity generated than do plants using recirculating cooling systems. For water consumption, however, once-through cooling has lower demands than recirculating systems. Dry cooling can be used to reduce both withdrawal and consumption for thermal plants but at a cost and efficiency penalty (EPA 2009). Non-thermal RE technologies, such as photovoltaics and wind, do not require water for cooling and thus have low operational water-use intensities. All new concentrating solar power capacity is modeled with cost and performance characteristics consistent with dry cooling, landfill gas facilities are assumed to require no water for operations, and hydropower evaporation is not considered.

Electric-sector water savings provide economic and environmental benefits, especially in regions where water is limited and could be used for other ecosystem or societal services. Reducing electric sector dependence on water can also reduce the vulnerability of electricity supply to the availability or temperature of water, and help ease concerns over energy sector vulnerabilities to climate change (DOE 2013). And the lower life-cycle water requirements of some renewable technologies can help alleviate other energy-sector impacts on water resource quality and quantity that take place during upstream fuel production for other technologies (Averyt et al. 2011). Because there is no standard, literature-based methodology to quantify the monetary benefits of these water-use reductions (DOE 2015, we do not quantify the benefits of water-use reductions in monetary terms.

Gross Renewable Energy Workforce Requirement and Economic Development Impacts

We estimate the potential gross domestic RE-related jobs and other economic impacts associated with the Existing RPS and High RE scenarios relative to the No RPS scenario. Such estimates may provide governments, stakeholders, and other interested parties information about how RE expenditures could translate to gross RE workforce needs and associated gross domestic product, earnings, and economic activity in the United States.

It must be emphasized, however, that our analysis does not include an assessment of economy-wide net impacts, and we therefore make no claim of net benefits or costs.[39] Accordingly, we refer to the estimated RE workforce and economic effects as impacts rather than benefits. Impacts such as displacement of jobs in fossil fuels or displaced investment in general are not included.

[39] Increased renewable generation displaces demand for other sources of electric generation, impacting job totals and economic development associated with those sectors. Additionally, to the extent that increased renewable energy impacts the cost of energy, or has other macroeconomic effects, this too may affect employment in the broader economy. In general, there is little reason to believe that net impacts are likely to be sizable in either the positive or negative direction, at least at an international or national scale (e.g., Rivers 2013). Moreover, even were net positive effects likely, questions remain as to whether such effects serve as economic justification for government policy (e.g., Borenstein 2012; Edenhofer et al. 2013; Gillingham and Sweney 2010; Morris et al. 2012).

To assess the potential gross RE-related workforce requirements and economic-development impacts of the Existing RPS and High RE scenarios, we use NREL's Jobs and Economic Development Impacts (JEDI) suite of models as well as IMPLAN, applying those models to estimate the gross impacts associated with ReEDS-estimated capacity additions and generation of wind, solar, geothermal, landfill gas, hydropower, and biomass. JEDI is an input-output model based on IMPLAN and has been used extensively in national and regional assessments. Because there is no landfill gas module in the JEDI suite, we use IMPLAN parameterized with cost assumptions from Jensen et al. (2010). Assumptions for "domestic content"—the portion of expenditures made in the United States—for RE technologies are based on JEDI default data and Jensen et al. (2010).[40,41]

We estimate gross domestic job needs and economic development impacts associated with both the operation and construction (including domestic manufacturing of equipment subsequently installed) of RE facilities. Four metrics are presented: gross jobs, earnings, output, and gross domestic product. Jobs are expressed as full time equivalent, which is the same as one job-year, the equivalent of one person working 40 hours per week for one year. Earnings include wages, salaries, and employer-provided supplements such as health insurance and retirement contributions. Output is a measure of overall economic activity. At an individual business, it could be thought of as revenue. This revenue includes payments for inputs as well as payroll and taxes, and property-type payments (including profits or payments to investors). Gross domestic product is solely a measure of the value of production. It includes payments to workers, property-type income, and taxes.

These four metrics can be segmented into three categories: onsite, supply chain, and induced. Onsite impacts are most directly related to the project; these include installers, construction workers, plant operators, and other maintenance personnel. Supply chain impacts arise as a result of domestic expenditures by the developer, installer, or operator; these include construction material providers, equipment manufacturers, and consultants. Induced impacts arise as a result of onsite and supply chain workers making expenditures within the United States; these impacts are often in retail sales, leisure and hospitality, education, and health services. In all cases, we only report domestic jobs and impacts. All results produced by JEDI and IMPLAN are for the equivalent of a single year, although results are presented in both single years and cumulatively over multiple years (e.g., 2015–2050). Results are reported on a national basis and, for onsite jobs only, on a regional basis.[42]

Aside from only estimating gross impacts, there are several limitations to using input-output models such as JEDI and IMPLAN. Perhaps most importantly, these models do not make assumptions about future changes in the economy such as technology improvements, changes in relative prices, or changes in tax rates that could cause producers to substitute inputs or change how much they purchase in the United States. Model results should therefore be interpreted as gross impacts that could take place given the structure of the economy as it exists at the time of publication of this report.

Natural Gas Price Reduction Impacts

Though RE is not free of risk, it relies on a domestic "fuel" stream not subject to significant resource exhaustion or price uncertainty. Various methods have been used to assess the benefits of these characteristics as well as the benefits of electricity supply diversity more generally (Awerbuch 1993;

[40] Default data are used to ensure that each technology is treated as similarly as possible to maintain consistency. Model estimates using default data have historically come close to job counts at actual projects and numbers published by other researchers (Billman and Keyser 2013).
[41] Domestic content is specified for project expenditures.
[42] We do not estimate supply chain or induced economic impacts by region because of uncertainty relating to where in the United States those impacts take place.

Bazilian and Roques 2008; Bolinger 2013; Bolinger et al. 2006; Jenkin et al. 2013; Stirling 2010; Wiser and Bolinger 2006). Many of these methods have proven to be incomplete or even controversial, however, and standardized approaches to benefit quantification have not emerged.

Increased use of RE mitigates long-term fossil fuel price risks in one way that can be readily quantified. Specifically, by reducing demand for fossil fuels, RE can place downward pressure on fossil fuel prices with benefits to energy consumers both within and outside of the electricity sector. We estimate these effects for the Existing RPS and High RE scenarios relative to the No RPS scenario, focusing on impacts to natural gas prices.[43]

Specifically, ReEDS is used to estimate the impact of the various scenarios on natural gas demand and regional gas prices; these price impacts are estimated within ReEDS based on results from the EIA's *Annual Energy Outlook* model scenarios.[44] Natural gas price impacts within the electric sector are addressed within ReEDS and are embedded within the cost and electricity price metrics discussed earlier. The effects of natural gas price changes outside of the electric sector, however, are not included within ReEDS. To estimate these consumer natural gas bill savings we apply the regional natural gas price changes estimated by ReEDS to EIA estimates of future non-electric sector regional gas demand.[45]

These consumer natural gas bill savings come at the expense of natural gas producers and so represent a transfer payment. While individual states may experience net benefits from these transfers—e.g., states that consume more natural gas than they produce—others may experience the opposite. We therefore refer to this effect as an impact rather than a benefit and make no claim of a net societal gain.

[43] Within a simple economics supply/demand framework, this gas price effect can be represented by the demand curve for natural gas shifting inward along the supply curve. Presuming the supply curve has an upward slope and does not change in response to the demand shift, the demand shift will result in a lower price. Although demand for coal within the electricity sector also declines as a result of increased renewable generation, we do not analyze potential impacts on coal prices because the long-term inverse price elasticity of supply is generally thought to be lower for coal than for natural gas (Wiser and Bolinger 2007).

[44] Cole, Medlock, and Jani (2016) and Eurek et al. (2016) describe the methodology behind the regional and national natural gas supply curves (price vs. electric sector consumption) used in ReEDS. The parameterization of these supply curves are based on data from scenarios in the EIA Annual Energy Outlook (EIA 2014; EIA 2016).

[45] There is inherent uncertainty in the response of natural gas prices to natural gas demand. The results estimated here are consistent with assumptions and approaches used by EIA, but are inherently uncertain. Consistent with EIA, we further assume that national wellhead gas price changes flow through fully to delivered natural gas prices in all regions and across all sectors, and that consumers are fully exposed to those price changes. We do not fully account for the possibility that any price changes could yield a rebound in natural gas demand, including possibilities for natural gas exports.

3. Renewable Deployment and Avoided Fossil Generation under Existing RPSs and Expanded RE Scenarios

This section describes projected annual energy generation and installed capacity by technology type under each of the scenarios examined in the analysis. Differences in generation and capacity across the scenarios are the basis for the estimated costs, benefits, and other impacts presented in Sections 4 and 6.

Figure 3.1 shows the RE penetration as a fraction of total annual generation under each of the three scenarios, as calculated by the ReEDs model. By 2030, renewables (including hydropower) are estimated to grow to 26% of energy generation under the Existing RPS scenario, compared to 21% under the No RPS scenario and 35% under the High RE scenario. These estimates are up from a 14% renewable penetration level in 2015, of which about half consists of hydropower. By 2050, renewables reach 34% under the No RPS scenario, 40% under the Existing RPS scenario, and 49% under the High RE scenario. The general trends in RE penetration shown in Figure 3.1—rapid growth through 2020, followed by steady or flat growth between 2020 and 2040, and increasing growth rates after 2040—are primarily driven by the underlying policy, technology cost, and fuel price assumptions. More specifically, the modeling analysis finds that the federal RE tax credits to be effective at driving significant RE growth in the near term, but after their expirations, growth in RE generation does not significantly exceed demand growth. In the longer term, the scenarios show that the assumed reductions in RE technology costs combined with increasing natural gas prices result in rapid RE growth during the last decade of the analysis.[46]

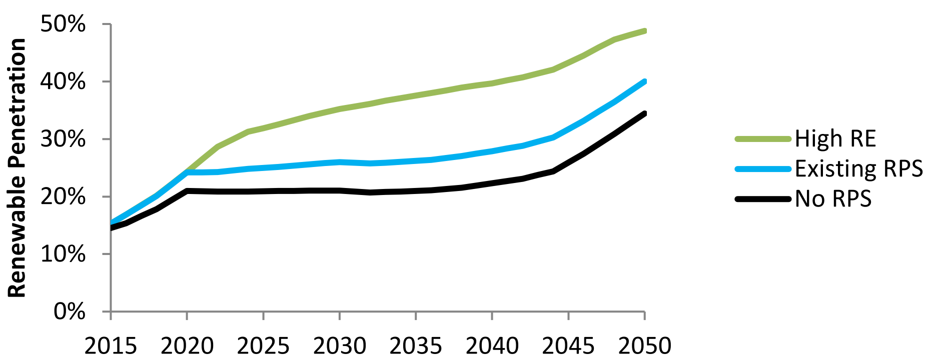


Figure 3.1. U.S. renewable energy penetration under three modeled scenarios

The Existing RPS scenario leads to 66 gigawatts (GW) of renewables above the No RPS scenario by 2030, or an additional 218 terawatt-hours (TWh) of renewable generation in 2030 (see Figure 3.2).[47] Most of the additional capacity and generation is composed of wind and solar, but there is also significant incremental generation from biomass and geothermal. Specifically, by 2030, the Existing RPS scenario shows an additional 42 GW of solar (both utility scale and distributed), 19 GW of wind, and the remaining 5 GW from biomass, geothermal, and hydropower. On a generation basis, contributions are

[46] The NREL 2016 Standard Scenarios report (Cole et al. 2016) provides results and discussion of a broader set of scenarios that use very similar, though not precisely the same, assumptions as the scenarios here.

[47] The Existing RPS scenario allows for economic RE deployment, i.e. deployment beyond the RPS requirements. For example, we estimate annual RE generation to grow by nearly 600 TWh between 2014 and 2030, and by about 1570 TWh by 2050; these levels well exceed the increase in estimated growth in RPS requirements over the corresponding periods.

more evenly spread across technologies, with solar contributing 83 TWh, 74 TWh from wind, and 61 TWh from the combination of biomass, geothermal, and hydropower in 2030.[48]

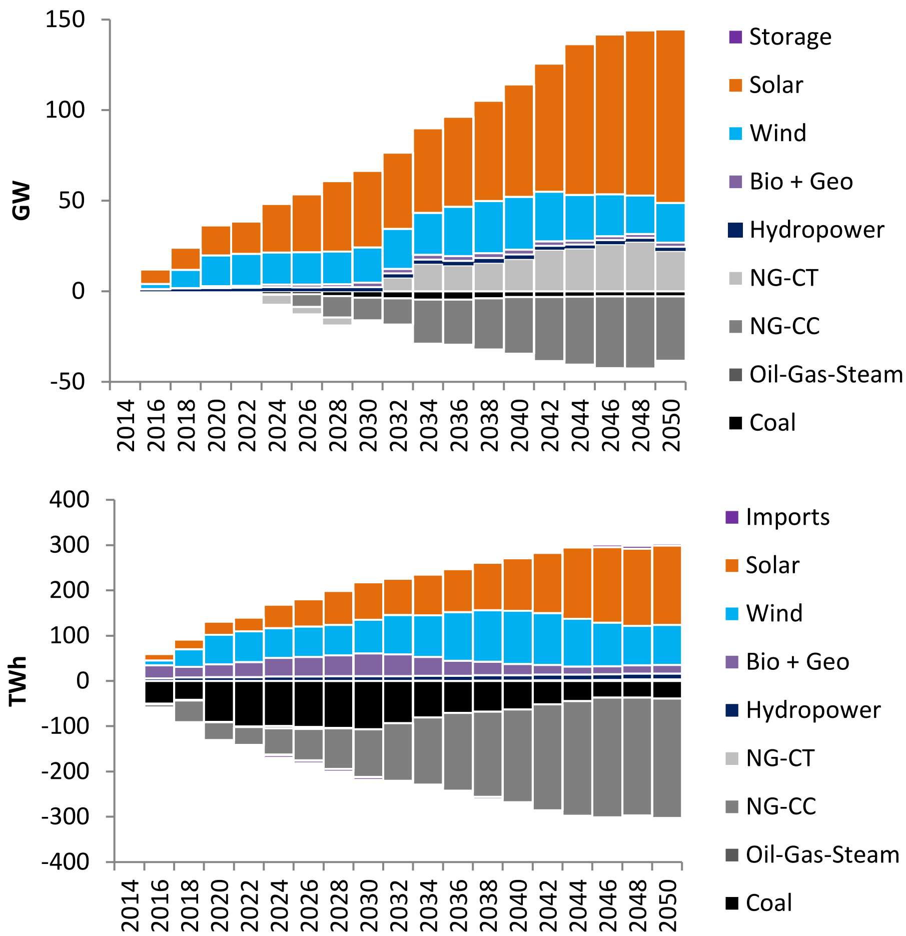


Figure 3.2. Difference in capacity (top) and generation (bottom) between the Existing RPS and No RPS scenarios through 2050

By 2050, the Existing RPS scenario requires an additional 122 GW of renewable capacity beyond that in the No RPS scenario, or 296 TWh of incremental RE generation. Solar represents a substantially larger fraction of the incremental capacity and generation in the 2050 timeframe.

The new RE generation in the Existing RPS scenario largely offsets fossil generation, with a greater amount of coal offset before 2030 but more natural gas offset in the longer term. In 2030, the renewable generation fairly evenly offsets coal generation and natural gas generation from combined cycle units (see Figure 3.2). By 2050, the vast majority of displaced generation is from natural gas combined cycle units. Avoided fossil capacity is also found in the Existing RPS scenario with nearly 40 GW of avoided natural gas combined cycle capacity by the 2040s and additional coal capacity retirements of less than about 5

[48] The scenario outcomes between renewable technologies can be sensitive to the assumptions used. Given uncertainties associated with future technology costs, different technology distributions for RE used to meet growing RPS requirements from those in Figures 3.2 and 3.3 are ultimately likely. However, we note that prior studies (DOE 2015; DOE 2016; Wiser et al. 2016b) have found similar benefits between different RE options.

GW.[49] However, we find greater deployment of natural gas combustion turbine peaking capacity in the Existing RPS scenario compared with the No RPS scenario. This result, which is most prominent in the long term after 2030, reflects the need for firm capacity with growing electricity consumption. On net, fossil capacity is lower in the Existing RPS compared to the No RPS scenario, suggesting that the incremental RE from the former scenario possesses some capacity credit.

The High RE scenario results in 215 GW of renewables above the No RPS scenario by 2030, or 627 TWh of incremental renewable generation (see Figure 3.3). Wind and solar are the dominant RE technologies deployed in the High RE scenario, although we estimate some incremental biomass, geothermal, and hydropower generation in the 2030 timeframe. Specifically, the High RE scenario includes an incremental 137 GW of solar and 71 GW of wind. On a generation basis, the incremental wind and solar generation are of very similar magnitude (280 TWh wind, 273 TWh solar), while biomass, geothermal, and hydropower contribute an additional 73 TWh above the No RPS scenario by 2030.

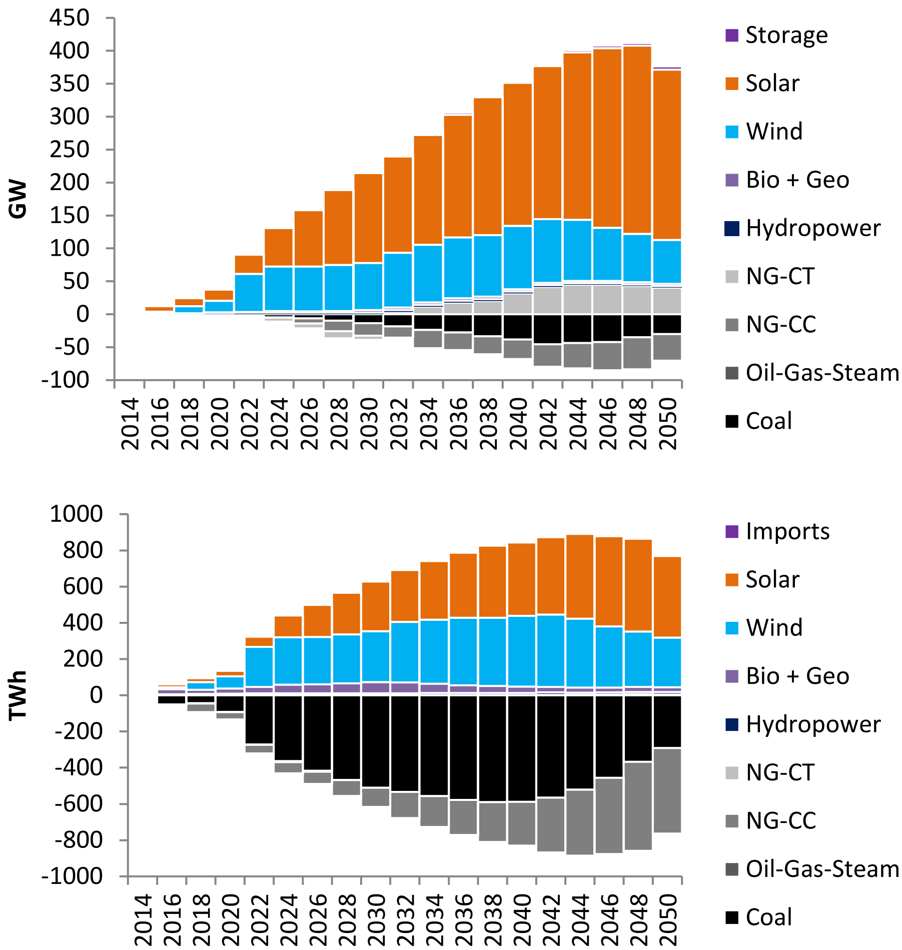


Figure 3.3. Difference in capacity (top) and generation (bottom) between the High RE and No RPS scenarios through 2050

[49] ReEDS does not install new coal capacity in any of the scenarios. Differences in coal capacity reflect greater retirements of coal plants with high RE shares. Coal retirements in ReEDS are modeled based on lifetimes, announced retirements, and estimated utilization (Eurek et al. 2016). The latter method is responsible for any differences in coal capacity between the scenarios.

In the longer term, by 2050 the High RE scenario requires 331 GW of RE capacity above the No RPS scenario, or 765 TWh of incremental renewable generation. By 2050, capacity additions are dominated by solar, but there is also significant incremental wind and natural gas combustion turbine capacity compared to the No RPS scenario. Incremental generation in 2050 is still split relatively evenly between solar and wind.

Coal is the dominant form of avoided generation in the High RE scenario, even more so than in the Existing RPS scenario. In 2030, more than 80% of the displaced fossil fuel generation is coal, with the remainder primarily from natural gas combined cycle units. In the longer term, more natural gas generation is displaced, but coal displacement is still substantial.

Figure 3.4 further highlights the differences in cumulative displacement of fossil generation under the Existing RPS and High RE scenarios relative to the No RPS scenario, as well as how displacement changes in the near term (before 2030) and the longer term. While the Existing RPS scenario offsets more natural gas in the longer term, the High RE scenario displaces substantial coal generation in both the short and longer term. Under the Existing RPS scenario, more than half of cumulative displacements are coal generation in the near term, but coal falls to about one-third of displacements in the longer term as more natural gas generation from combined cycle units is displaced. For the High RE scenario, coal represents more than 80% of cumulative displacements in the near term, and a little more than two-thirds of displacements in the longer term.

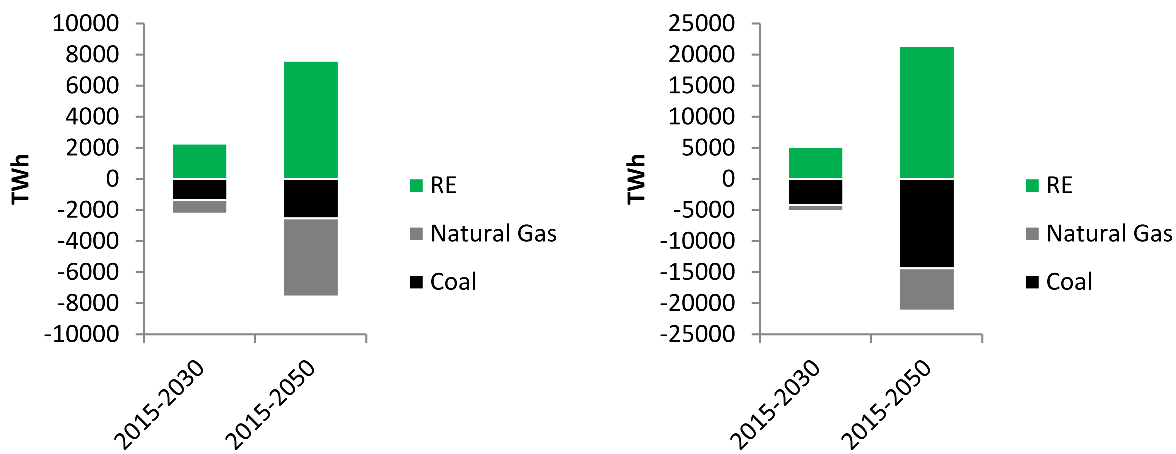


Figure 3.4. Difference in cumulative generation between the Existing RPS (left) and High RE (right) scenarios relative to No RPS

The amount and type of displaced fossil generation is explained in part by regional deployment of renewables as well as the assumed drivers behind incremental RE deployment in the scenarios. For the Existing RPS scenario, regional variations in renewable generation depend on state RPS policies, including the magnitude and timing of RPS targets, while fossil displacement is also affected by other regional factors such as the existing generator fleet, anticipated coal plant or other plant retirements, and future fuel prices. In general, states with RPS policies are typically not as coal-reliant as non-RPS states, thereby resulting in relatively low levels of avoided coal generation in the Existing RPS scenario. In contrast, the High RE scenario effectively applies to all states. Moreover, emission constraints are the primary drivers in the High RE scenario compared to the direct RE requirements under the Existing RPS scenario. As a result, the High RE scenario results in much greater levels of avoided coal generation than in the Existing RPS scenario.

Figure 3.5 shows cumulative RE generation for the Existing RPS scenario and High RE scenario relative to the No RPS scenario in the nine census divisions. Under the Existing RPS scenario, the Pacific region in particular results in substantial incremental RE generation in the near term as well as the longer term. Other regions with lesser but still substantial incremental renewable generation under the Existing RPS scenario, particularly by 2050, include the East North Central region, the Middle Atlantic, New England, and the Mountain region. Notably and as described previously, the significant RPS-required renewable generation in New England and the Pacific region largely offsets gas while smaller amounts of incremental renewables elsewhere help reduce more coal.

In general, the distribution of incremental renewable generation is more uniform in the High RE scenario. The greatest absolute amounts of incremental renewables under the High RE scenario are found in the Midwest (East and West North Central regions), Pacific, and South Atlantic regions. On a percent basis, incremental renewable generation is even more uniformly distributed between census regions.

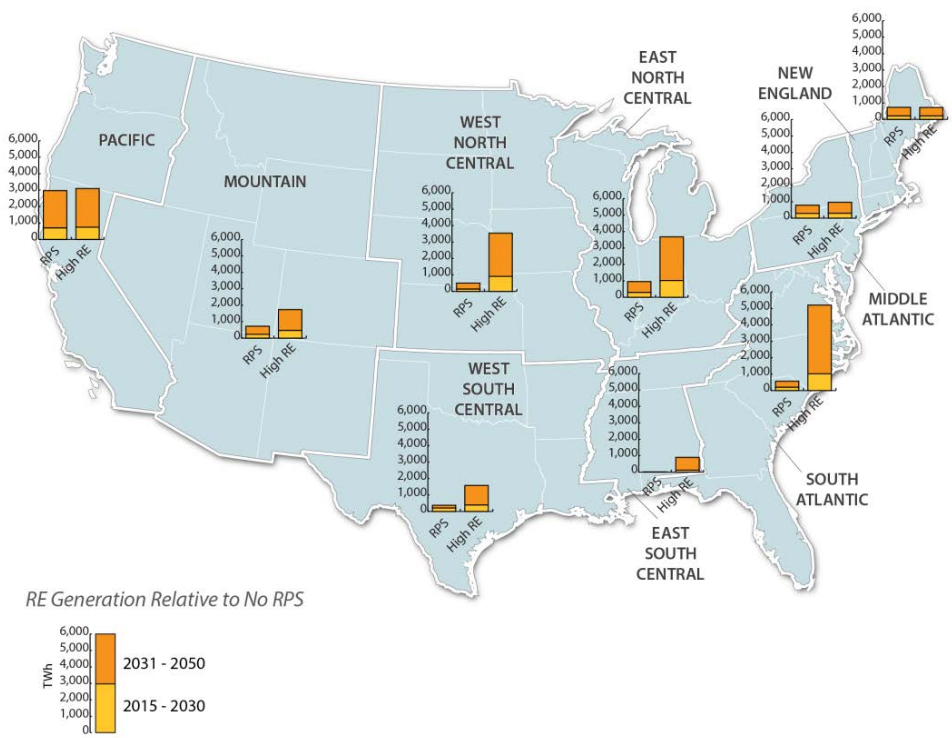


Figure 3.5. Regional incremental RE generation relative to No RPS

4. Costs of Existing RPSs and Expanded RE

The ReEDS model directly estimates costs in each scenario. Here we present those results by comparing costs for the Existing RPS and High RE scenarios relative to the No RPS scenario in terms of the two cost metrics introduced earlier: (1) the net present value of system costs, and (2) average retail electricity prices. For both metrics, we present the results in terms of the *incremental* cost relative to the No RPS scenario. Rather than focusing on central-case cost estimates, we instead present the *range* in incremental costs across sensitivity cases related to natural gas prices and renewable technology costs.[50]

We also compare the estimated *prospective* incremental electric system costs with historical compliance costs reported by utilities, state regulatory agencies, and others (Heeter et al. 2014; Barbose et al. 2015).

System Costs

The national electric system costs presented in Figure 4.1 are based on the net present value of all electric system expenditures from 2015 to 2050, including fuel, O&M, and capital costs for new generation, interconnection, transmission, and storage infrastructure. For the Existing RPS scenario, incremental costs were estimated to range from ±$31 billion (-0.7% to 0.8% on a national basis inclusive of the states with and without RPS polices) relative to the No RPS scenario. On a levelized basis, this equates to about ±0.75 cents per kWh of renewable electricity (¢/kWh-RE).[51] The fact that the low end of the cost range is negative implies that, under certain conditions (namely, high natural gas prices or low renewable energy technology costs), RE used to meet existing RPS policies results in a net savings to the electric system. Conversely, when gas prices are relatively low or when renewable energy technology costs are high, RE used for existing RPS requirements results in a net cost. In either case, however, the net effect (whether positive or negative) is quite small as a share of overall system costs.

For the High RE scenario, the range in incremental system costs is much wider. Under this scenario, incremental system costs ranged from $23 billion (0.6% of total system costs) to $194 billion (4.5% of total system costs) across the sensitivity cases. This equates to 0.26¢/kWh-RE to 1.5¢/kWh-RE on a levelized basis. The upper bound of the range corresponds to the sensitivity with high RE technology costs.

[50] Whereas the benefits and impacts presented in Sections 5 and 6 are based only on scenarios using *central* assumptions for renewable energy technology costs and natural gas prices.

[51] Reported levelized system costs are defined as the incremental present value of system costs (in dollars) divided by the present value of incremental RE generation (in kilowatt-hours or megawatt-hours) relative to the No RPS scenario. We use a 3% real discount rate for both present value calculations.

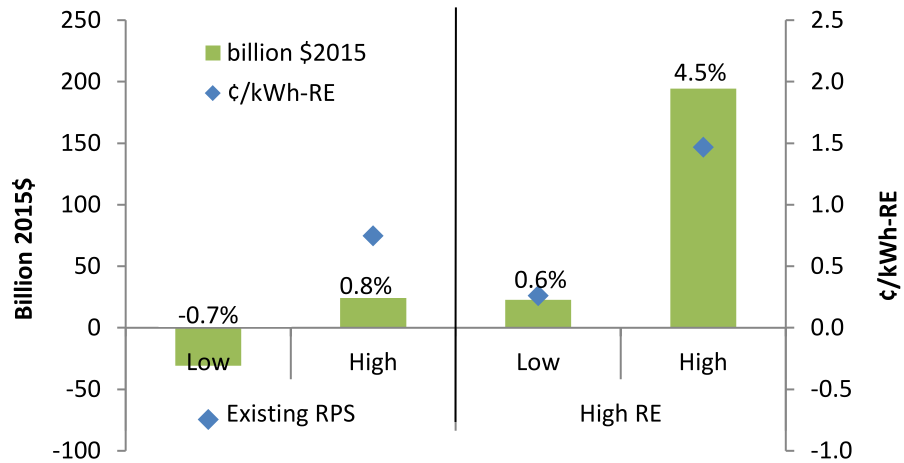


Figure 4.1. Present value incremental system cost compared to No RPS, 2015–2050

As a point of comparison, previous work by Lawrence Berkeley National Laboratory and NREL estimated historical RPS compliance costs based on data reported by utilities, state regulatory agencies, and others (Barbose et al. 2015; Heeter et al. 2014).[52] Those analyses and subsequent data updates found that for 2012–2014, the incremental cost of RPS compliance averaged around 1¢/kWh-RE, though costs varied by state. This is roughly in line with the upper end of the range estimated here for the Existing RPS scenario, which is about 0.75¢/kWh-RE.

Electricity Prices

Figure 4.2 shows average electricity prices in the Existing RPS and High RE scenarios relative to the No RPS scenario, with ranges reflecting variations across sensitivity cases as well as across regions. A positive number implies higher electricity prices and a negative number implies lower electricity prices than in the No RPS scenario. One important difference relative to the incremental system costs described earlier is that the modeled impacts on electricity prices reflect RE tax credits (which are not included when calculating system costs for reasons noted previously). As a result, the incremental effects on electricity prices tend to be lower than the effects on system costs.

Based on our modeled results, the Existing RPS scenario may result in up to roughly a 1¢/kWh increase in electricity prices on the high end. The upper-bound estimate generally grows until 2030 and stays relatively flat thereafter, with an average effect of about 0.7¢/kWh per year. On the low end of the range, the Existing RPS scenario results in a reduction in electricity prices relative to the No RPS scenario, although the magnitude of this effect varies significantly from year to year (and across regions).

For the High RE scenario, the upper bound to the range of electricity price effects is considerably higher than in the Existing RPS scenario. Specifically, relative prices are estimated to peak at about 4.2¢/kWh higher than the No RPS case with an average over all years of about 2.9¢/kWh. The low end of the range of incremental prices for the High RE scenario is similar to those for the Existing RPS scenario.

[52] As discussed in Section 2, our scenario constructs evaluate the impacts of all RE used to meet RPS demand growth. Incremental costs are estimated relative to the No RPS scenario, which has an upper limit on RE generation. Because of issues around additionality, these incremental values do not reflect directly the incremental cost of the RPS *policies,* and therefore care is warranted in comparing our reported incremental costs with other estimates.

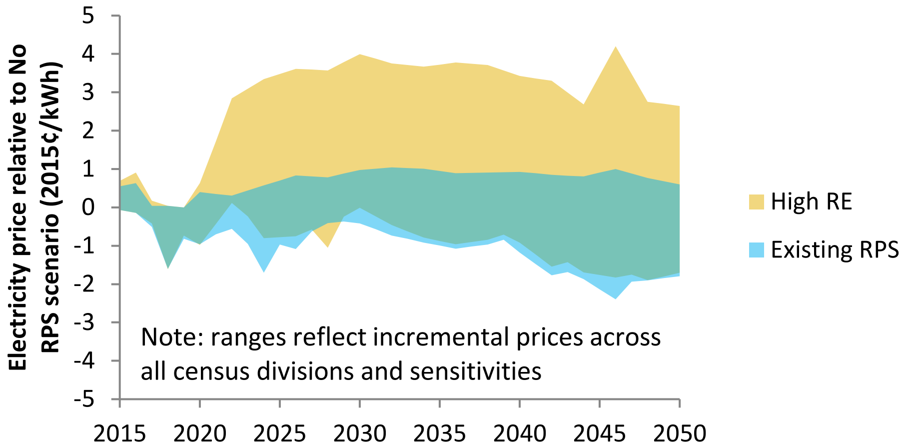


Figure 4.2. Range of electricity prices relative to No RPS scenario

While Figure 4.2 captures the full range of incremental prices across all regions and scenarios, electricity price impacts also vary across regions. Figure 4.3 shows the estimated range of 2030 incremental prices by census division across the full set of natural gas and renewable technology cost sensitivities. For the Existing RPS scenario, we find a narrow range of 2030 incremental prices. In most regions, 2030 incremental prices fall within a band of ±0.35¢/kWh. The New England and Pacific regions, which contain states with some of the more stringent RPS policies, are exceptions with 2030 incremental prices ranging from about -0.4¢/kWh up to about 1¢/kWh. For the High RE scenario, high-end 2030 incremental prices are estimated to be highest in the New England (4¢/kWh) and Middle Atlantic (3.6¢/kWh) regions. All other regions have high-end 2030 incremental price estimates in the range of 2–3.2¢/kWh. On the low end of the ranges, regional 2030 incremental prices for the High RE scenario vary from -0.1¢/kWh (Pacific region) to about 0.4¢/kWh (New England and Middle Atlantic regions).

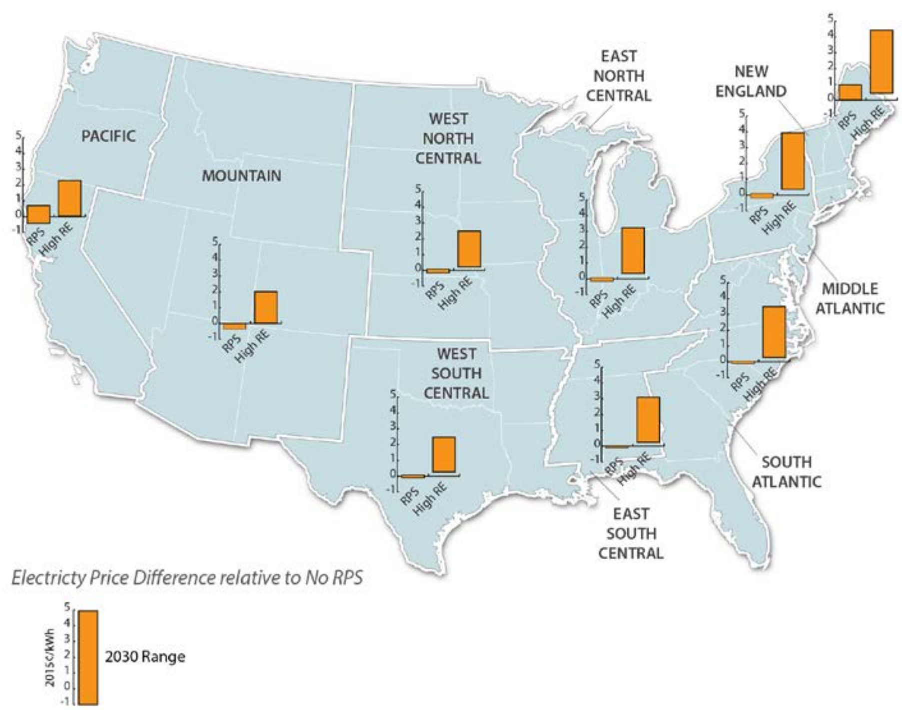


Figure 4.3. Regional ranges of 2030 retail electricity prices relative to No RPS scenario

5. Benefits of Existing RPSs and Expanded RE

Using the methods discussed earlier, we evaluate three potential benefits associated with the Existing RPS and High RE scenario, both relative to the No RPS scenario:[53]

- Air pollutant emissions and human health and environmental benefits
- GHG emissions reduction benefits
- Water use reduction benefits.

We report results in physical units and—where credible methods exist—in monetary terms.

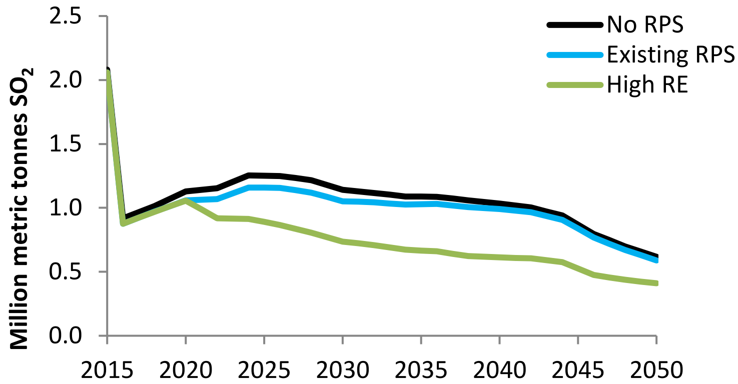
Air Pollutant Emissions, Human Health, and Environmental Benefits

The Existing RPS scenario reduces national electricity sector emissions of SO_2, NO_x, and $PM_{2.5}$ by 7.8%, 7.2%, and 6.0% in 2030 and by 4.6%, 5.0%, and 4.1% in 2050 relative to the No RPS baseline scenario (Figure 5.1). The High RE scenario drives greater reductions: SO_2 (35% in 2030, 34% in 2050), NO_x (34% in 2030, 32% in 2050), and $PM_{2.5}$ (33% in 2030, 32% in 2050). Percentage savings do not grow with time because, as shown earlier, greater proportions of natural gas are found to be offset (and lower proportions of coal) during the later years of the forecast period.

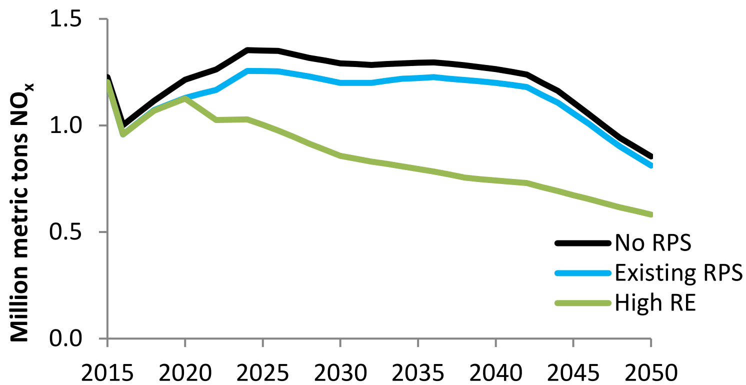
Cumulative emission savings under the Existing RPS scenario from 2015 to 2050 (and as a percentage of total electricity sector emissions) equal 2.1 million metric tons of SO_2 (5.5%), 2.5 million metric tons of NO_x (5.7%), and 0.3 million metric tons of $PM_{2.5}$ (4.5%). The High RE scenario leads to emission savings of 11.1 (29%), 12.8 (29%), and 1.8 (29%) million metric tons of SO_2, NO_x, and $PM_{2.5}$, respectively.

[53] The benefits and impacts presented in this section and the next are based only on scenarios using central assumptions for renewable energy technology costs and natural gas prices. The ranges presented reflect underlying uncertainties within each benefit or impact category but, unlike the cost results from Section 4, do not reflect the full range of scenario results.

(a) SO_2 emissions



(b) NO_x emissions



(c) $PM_{2.5}$ emissions

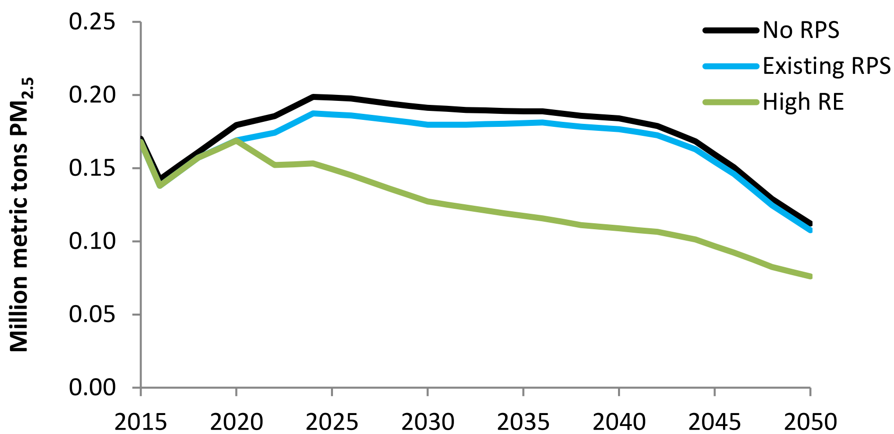
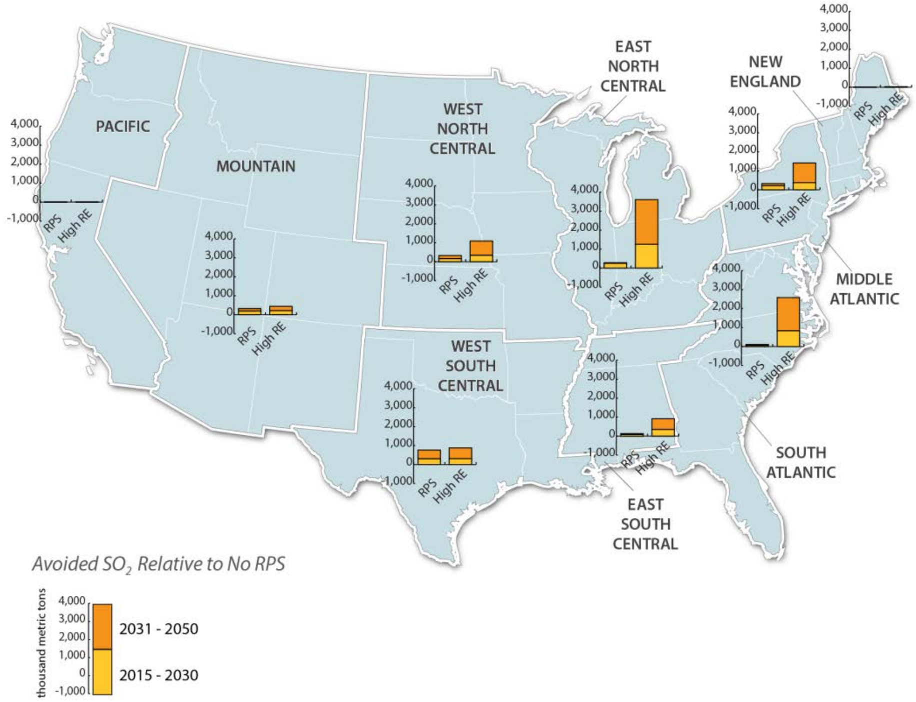


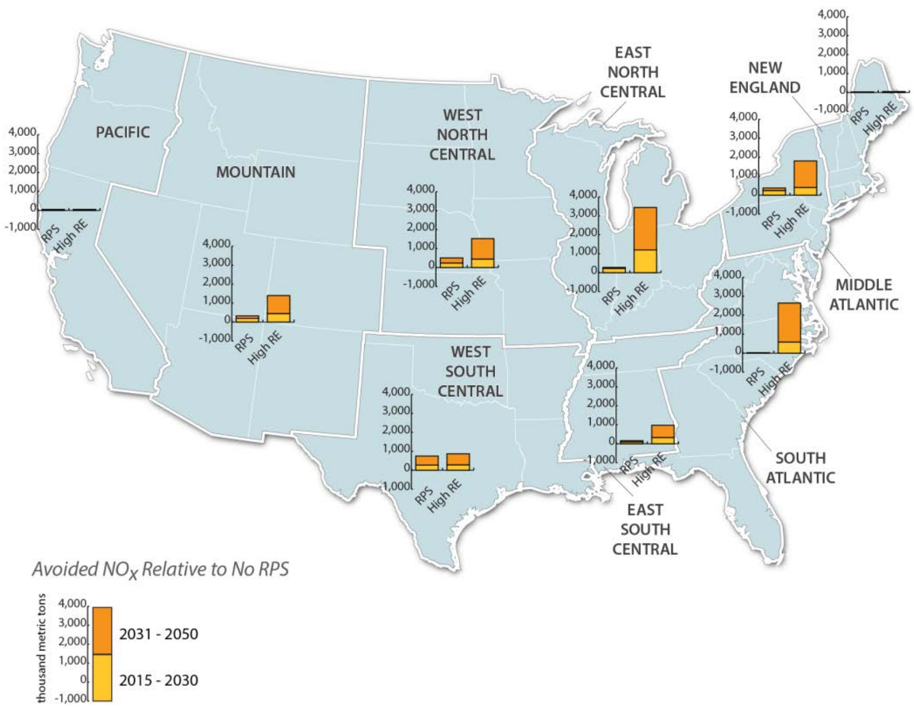
Figure 5.1. Emissions of (a) SO_2, (b) NO_x, and (c) $PM_{2.5}$ in three modeled scenarios

As shown in Figure 5.2, regional reductions are concentrated in areas with significant RE deployment that offsets coal-fired generation. Under the Existing RPS scenario, reductions are most sizable in the West South Central region. Under the High RE scenario, significant emission reductions accrue throughout much of the eastern half of the country, especially in the East North Central and South Atlantic areas. Some regions see small emissions increases under the Existing RPS and High RE scenarios; where this takes place, it is due to the estimated growth in biomass generation in these regions.

(a) SO_2 emissions



(b) NO_x emissions



(c) $PM_{2.5}$ emissions

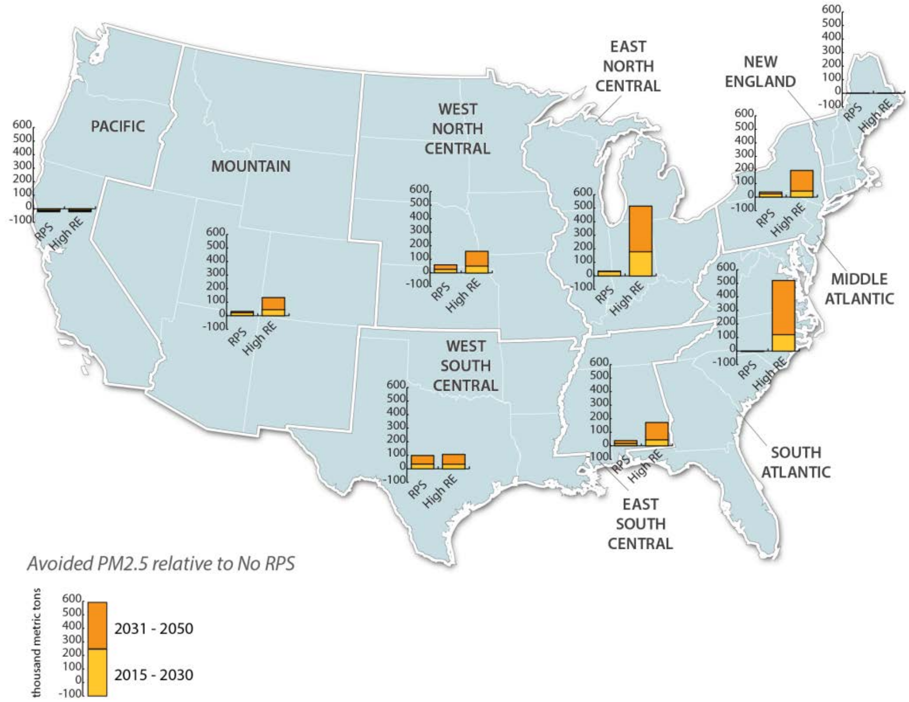


Figure 5.2. Regional (a) SO_2, (b) NO_x, and (c) $PM_{2.5}$ emissions relative to No RPS

All units in thousands of metric tons; note smaller scale for $PM_{2.5}$.

These emissions reductions lead to improved air quality and health outcomes across the continental United States. Estimates of the monetary value of these benefits are shown in Figure 5.3 (Existing RPS) and Figure 5.4 (High RE) across the full range of methods applied.

Existing RPS: Total health and environmental benefits from the Existing RPS scenario fall in the range of \$48–\$175 billion on a discounted, present-value basis. The average "central" estimate is \$97 billion, which is equivalent to a levelized benefit of RE of 2.4¢/kWh-RE; the total range is 1.2–4.2¢/kWh-RE (Figure 5.3). The range of benefits estimates reflects uncertainties in how to value emissions reductions.

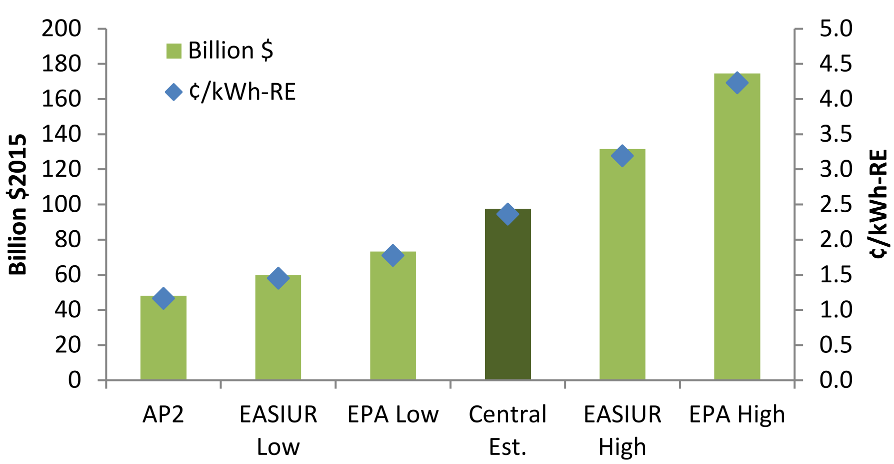


Figure 5.3. Present value (2015–2050) air pollution benefits, Existing RPS relative to No RPS

Note: The "Central Estimate" represents the simple average of all other estimates.

High RE: Under the High RE scenario, total benefits range from \$303 billion to \$917 billion on a present-value basis. The average "central" estimate is \$558 billion, which is equivalent to a levelized benefit of 5.0¢/kWh-RE; the total range is 2.7–8.2¢/kWh-RE (Figure 5.4). The divergence between the per-kilowatt-hour benefits of the High RE scenario relative to the Existing RPS scenario is again a consequence of the higher proportion of coal avoided under the former scenario.

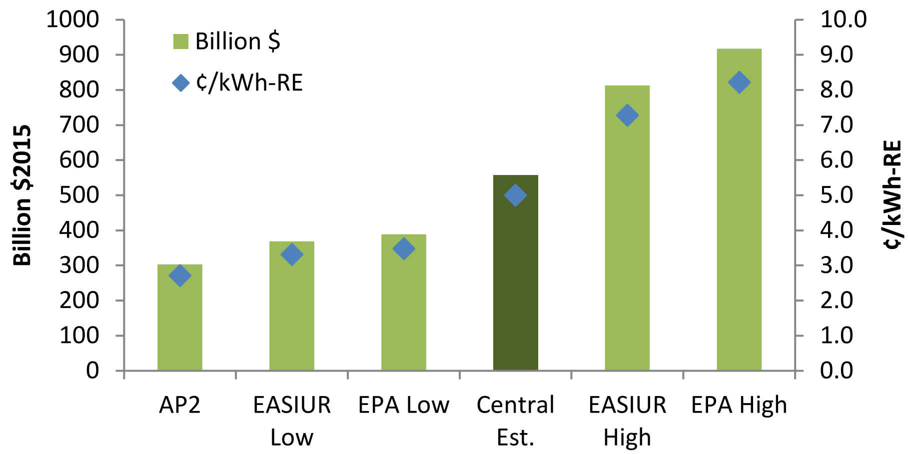


Figure 5.4. Present value (2015–2050) air pollution benefits, High RE relative to No RPS

Note: The "Central Estimate" represents the simple average of all other estimates.

Across both scenarios, reduction of SO_2 and the subsequent reduction of particulate sulfate concentrations account for the majority of the monetized benefits (Table 5.1). These benefits accrue primarily due to displacement of coal generation in the central and eastern United States.

Most of the health benefits come from avoided premature mortality, primarily associated with reduced chronic exposure to ambient $PM_{2.5}$ (largely derived from the transformation of SO_2 to sulfate particles, but also from transformation of NO_x to nitrate particles and direct $PM_{2.5}$ exposure). Based on the EPA approach, achieving the Existing RPS scenario prevents 12,000–28,000 premature mortalities in total from 2015 to 2050; the High RE scenario avoids 70,000 to 166,000 premature mortalities. These futures also result in numerous forms of avoided morbidity outcomes, as summarized in Table 5.1.

Table 5.1. Emissions reductions, monetized benefits, and mortality and morbidity benefits (2015–2050), Existing RPS and High RE relative to No RPS

	Exisiting RPS Benefits				High RE Benefits			
Impacts	**SO2**	**NOx**	**PM2.5**	**Total**	**SO2**	**NOx**	**PM2.5**	**Total**
Emissions Reductions (millions metric tons)								
RPS air pollution reductions	2.1	2.5	0.3	---	11.1	12.8	1.8	---
Total Monetized Benefits (Present Value - Billions 2015$)								
EPA Low benefits	56	10	7	73	291	52	45	388
EPA High benefits	126	34	15	175	645	174	98	917
EASIUR Low benefits	34	13	13	60	190	77	102	369
EASIUR High benefits	75	29	28	132	418	169	225	812
AP2 benefits	31	11	5	48	198	53	52	303
EPA Total Mortality Reductions								
EPA Low mortality reductions	9,000	2,000	1,000	12,000	53,000	9,000	8,000	70,000
EPA High mortality reductions	21,000	5,000	2,000	28,000	120,000	27,000	19,000	166,000
EPA Morbidity Reductions from Primary and Secondary $PM_{2.5}$ Impacts								
Emergency department visits for asthma (all ages)	3,000	300	400	3,700	13,500	1,400	2,500	17,400
Acute bronchitis (age 8-12)	12,500	1,300	1,500	15,300	71,000	7,300	11,200	89,500
Lower respiratory symptoms (age 7-14)	159,200	16,100	18,400	193,700	908,600	89,600	141,200	1,139,400
Upper respiratory symptoms (asthmatics age 9-11)	238,900	23,300	26,500	288,700	1,403,800	130,100	203,400	1,737,300
Minor restricted-activity days (age 18-65)	6,147,000	624,300	707,500	7,478,800	34,922,900	3,502,500	5,318,500	43,743,900
Lost work days (age 18-65)	1,010,400	101,100	116,400	1,227,900	5,700,000	555,100	870,600	7,125,700
Asthma exacerbation (age 6-18)	551,800	58,100	63,400	673,300	3,146,000	326,800	484,000	3,956,800
Hospital Admissions-Respiratory (all ages)	2,800	300	300	3,400	16,200	1,700	2,600	20,500
Hospital Admissions-Cardiovascular (age > 18)	3,500	400	400	4,300	21,000	2,200	3,200	26,400
Non-fatal Heart Attacks	10,600	1,100	1,300	13,000	62,600	6,200	9,900	78,700
Non-fatal Heart Attacks (Pooled estimates - 4 studies)	1,200	100	100	1,400	6,900	700	1,100	8,700
EPA Morbidity Reductions from NO_x --> Ozone Impacts								
Hospital Admissions, Respiratory (ages > 65)	---	4,400	---	4,400	---	25,400	---	25,400
Hospital Admissions, Respiratory (ages < 2)	---	1,900	---	1,900	---	9,900	---	9,900
Emergency Room Visits, Respiratory (all ages)	---	2,000	---	2,000	---	10,700	---	10,700
Acute Respiratory Symptoms (ages 18-65)	---	3,509,500	---	3,509,500	---	18,479,500	---	18,479,500
School Loss Days	---	1,162,400	---	1,162,400	---	5,925,600	---	5,925,600

Note: Monetized benefits are discounted at 3% (real), but emissions reductions and mortality and morbidity values are simply summed over the 2015–2050 period. EPA benefits derive from mortality and morbidity estimates based on population exposure to direct emissions of $PM_{2.5}$ and secondary $PM_{2.5}$ (from SO_2 and NO_X emissions) as well as ozone exposure from NO_X emissions during the ozone season (May–September). AP2 benefits are derived from mortality and morbidity estimates based on population exposure to direct emissions of $PM_{2.5}$ and secondary $PM_{2.5}$ (from SO_2 and NO_X emissions) as well as ozone exposure from NO_X emissions during the ozone season (May–September). AP2 benefits also include consequences from decreased timber and agriculture yields, reduced visibility, accelerated degradation of materials, and reductions in recreation services. EASIUR benefits derive from mortality estimates based on population exposure to direct emissions of $PM_{2.5}$ and secondary $PM_{2.5}$ (from SO_2 and NO_X emissions), but do not include morbidity benefits or ozone benefits. Morbidity incidences estimates are derived from EPA; unlike mortality estimates, EPA does not assign separate high and low estimates.

GHG Emissions Reduction Benefits

Achieving the Existing RPS scenario reduces life-cycle GHG emissions from the electricity sector by 7% in 2030 and 6% in 2050 relative to the No RPS baseline scenario (Figure 5.5). The High RE scenario results in far greater GHG reductions: 27% in 2030 and 25% in 2050. Cumulative GHG savings from 2015 to 2050 in the Existing RPS scenario equal 4.7 billion metric tons of CO_2-equivalent, representing 6% of total life-cycle emissions from the electricity sector over that same time period. Under the High RE scenario, GHG savings equal 18.1 billion metric tons, equivalent to 23% of total life-cycle emission in the electricity sector from 2015 to 2050.

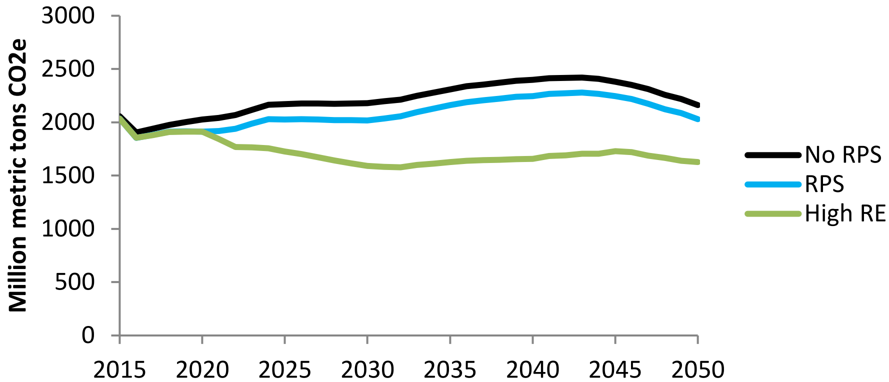


Figure 5.5. Electricity system life-cycle GHG emissions in three modeled scenarios

Emissions reductions from avoided fossil-fuel combustion (2015 to 2050) are estimated with ReEDS at 4.5 billion and 17.4 billion metric tons of CO_2 under the Existing RPS and High RE scenarios, respectively. These savings are somewhat smaller than the full life-cycle reductions, demonstrating that the emissions from the non-combustion phases of RE deployment are lower than for fossil fuels.

As shown in Figure 5.6, combustion-related CO_2 savings vary by region, timeframe, and scenario. Under the Existing RPS scenario, significant reductions accrue in most regions outside of the Southeast. Overall reductions are substantially greater in the High RE scenario and are particularly sizable in the East North Central and South Atlantic regions. These results are driven both by the relative amount and location of RE deployment in these scenarios and by the degree to which higher-carbon-emitting plants are displaced. The non-combustion, life-cycle impacts are not assigned to regions (and so are not included in Figure 5.6) because of the challenges of estimating the location of upstream and downstream emissions.

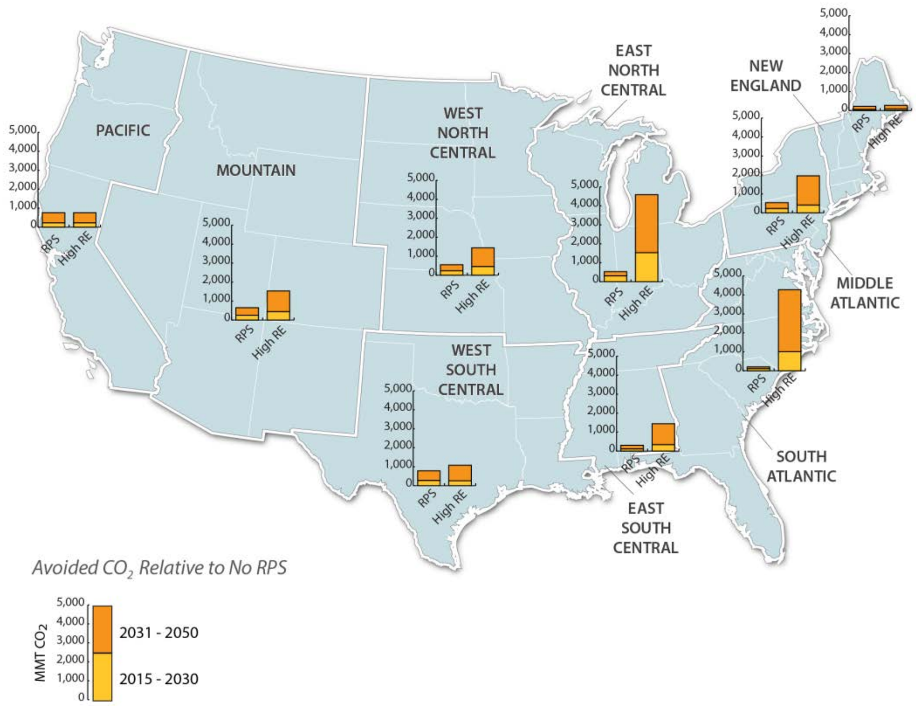


Figure 5.6. Regional avoided direct-combustion CO_2 emissions relative to No RPS

Estimates of the monetary value of these GHG emissions reductions are sizable but span a large range (see Figure 5.7 for Existing RPS and Figure 5.8 for High RE)[54]:

Existing RPS: Using the "central" trajectory for the SCC, discounted present-value global climate damage reductions from the Existing RPS scenario equal $161 billion. This is equivalent to a levelized benefit of RE of 3.9¢/kWh-RE. Across the full range of SCC estimates, total benefits span $37 billion (0.9¢/kWh-RE) to $487 billion (11.8¢/kWh-RE), a sizable range but significant even in the lower case. If, alternatively, RE is viewed as a way to meet future carbon-reduction requirements, then the present-value benefits of achieving the Existing RPS scenario range from $34 billion to $140 billion (0.8–3.4¢/kWh-RE) depending on the valuation approach used. Under Synapse's "medium" trajectory for the cost of carbon, the Existing RPS scenario yields $96 billion in savings, which is equivalent to a levelized benefit of 2.3¢/kWh-RE.

[54] In all cases, valuation estimates are based on emissions reductions that take place from 2015 through 2050: any emissions reductions after 2050 are not considered in the analysis.

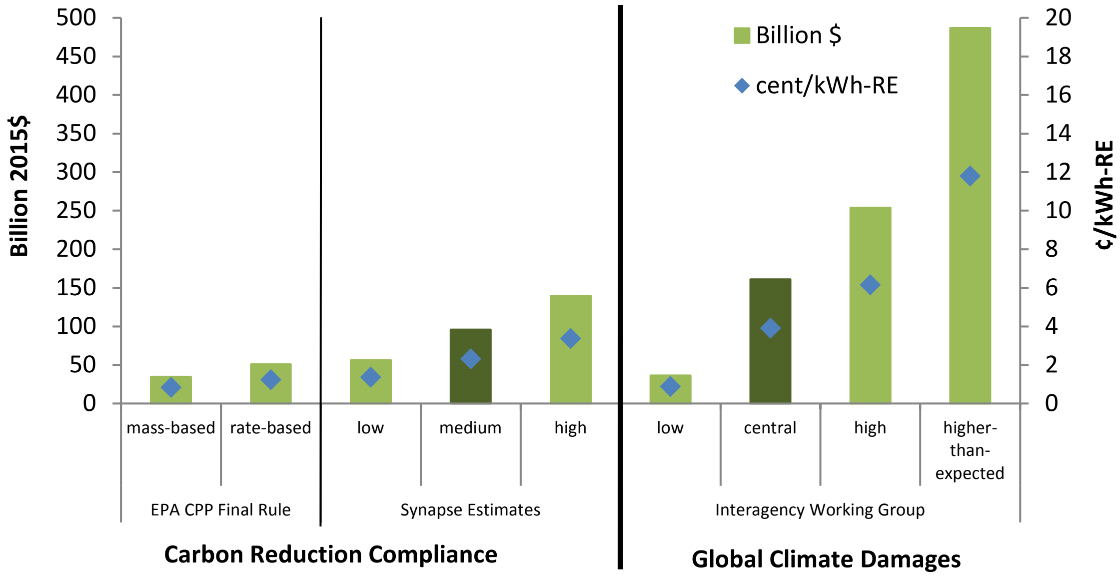


Figure 5.7. Present value (2015–2050) GHG reduction benefits, Existing RPS relative to No RPS

High RE: Using the "central" trajectory for the SCC, present-value global climate damage reductions from the High RE scenario equal $599 billion, equivalent to a levelized benefit of 5.4¢/kWh-RE. Across the full range of SCC estimates, benefits span $132 billion (1.2¢/kWh-RE) to $1,821 billion (16.3¢/kWh-RE). If, alternatively, RE is viewed as a way to meet future carbon-reduction requirements, then the present-value benefits of achieving the High RE scenario range from $131 billion to $614 billion (1.2–5.5¢/kWh-RE). Under Synapse's "medium" trajectory for the cost of carbon, the High RE scenario yields $418 billion in savings, which is equivalent to a levelized benefit of 3.8¢/kWh-RE. The per-kilowatt-hour benefits of the High RE scenario are greater than for the Existing RPS scenario due to the larger proportion of coal (and lower proportion of natural gas) that is offset by growth in RE.

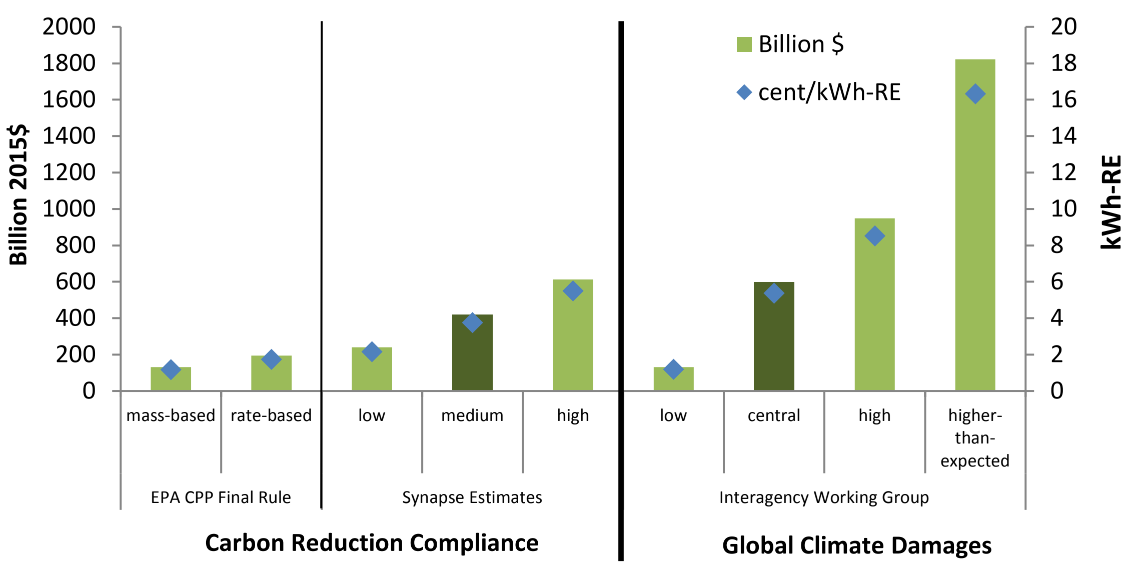


Figure 5.8. Present value (2015–2050) GHG reduction benefits, High RE relative to No RPS

WATER USE REDUCTION BENEFITS

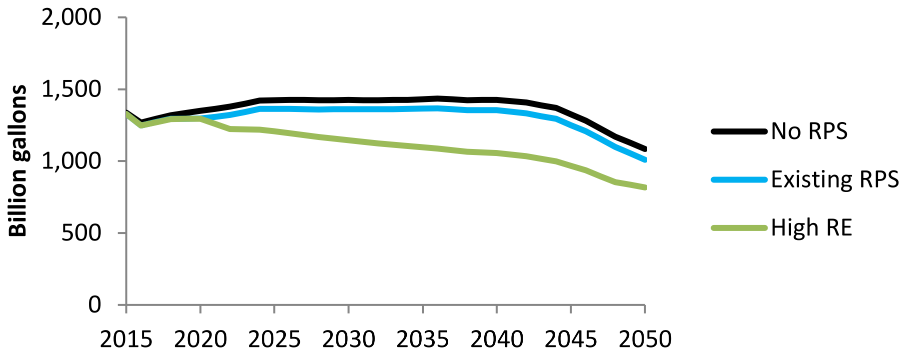
On a national level, electricity sector water withdrawals are estimated to decline substantially over time under all scenarios, largely owing to the retirement and reduced operations of once-through-cooled thermal facilities and the assumed replacement of those plants with newer, less water-intensive generation and cooling technologies (Figure 5.9). National electricity sector water consumption also eventually declines in all scenarios, but to a lesser extent than water withdrawals because recirculating cooling has higher water consumption than once-through cooling.

Achieving the Existing RPS and High RE scenarios further reduces electricity sector water use, both compared with recent use and compared with the No RPS baseline scenario (Figure 5.9). Specifically, under the Existing RPS scenario, water consumption is 4% lower in 2030 and 7% lower in 2050 relative to the No RPS baseline, and water withdrawal is 4% lower in 2030 and 3% lower in 2050. On a cumulative basis (2015–2050), water consumption and withdrawal savings are 4% (2,200 billion gallons) and 3% (26,000 billion gallons) lower, respectively, in the Existing RPS scenario. Greater impacts are seen in the High RE scenario: relative to the No RPS baseline, water consumption is 20% lower in 2030 and 25% lower in 2050, whereas water withdrawal is 20% lower in 2030 and 26% lower in 2050. Cumulative water use is estimated to be 18% lower in the High RE scenario, with about 9,000 billion gallons in in reduced water consumption and 169,000 billion in reduced water withdrawal.

To put these figures into context, the 2030 annual consumption savings are equivalent to the water demands of 420,000 U.S. households in the Existing RPS scenario, and 1.9 million households in the High RE scenario. On average and over the entire 2015–2050 period, each megawatt-hour of RE meeting the Existing RPS targets is found to save 3,400 gallons of water withdrawal and 290 gallons of water consumption.

Water consumption and withdrawal impacts are not uniform throughout the continental United States. Figure 5.10 presents regional cumulative water savings (2015–2050) in absolute terms and as a percent of power sector water use compared with the No RPS baseline for 18 distinct watershed regions. The amount of water saved—whether consumption or withdrawal—is affected by the amount and type of incremental RE supply and the water use associated with the displaced fossil generation units. Given these dynamics, the largest water savings—especially under the High RE scenario—accrue in regions of the United States that are not generally considered water stressed and that currently withdraw and consume larger quantities of water for power generation. Figure 5.10 highlights that although absolute water withdrawal and consumption savings are lower in the water-stressed southwestern United States, the percent savings under the Existing RPS scenario are more-consistent with savings in other regions. Under the High RE scenario, absolute and percent water savings are higher in regions other than the southwestern United States and water savings are typically greater than those found in the Existing RPS scenario. The watershed region comprising most of California shows a slight increase in cumulative water withdrawals by 2050, which are the result of higher generation levels of natural gas combined cycle technologies in California under the Existing RPS and High RE scenarios.

(a) Water consumption



(b) Water withdrawal

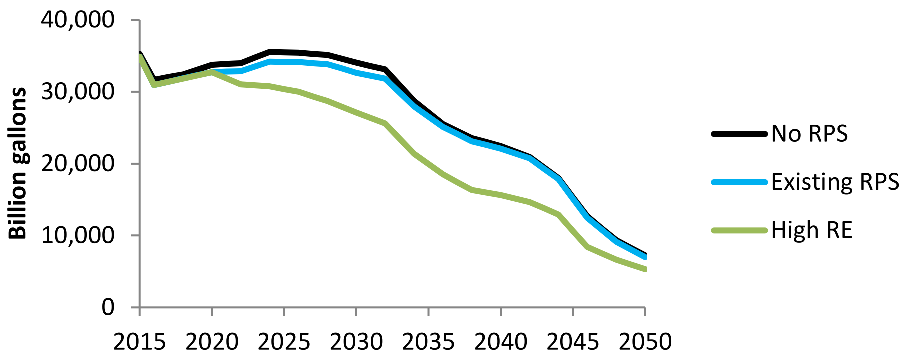
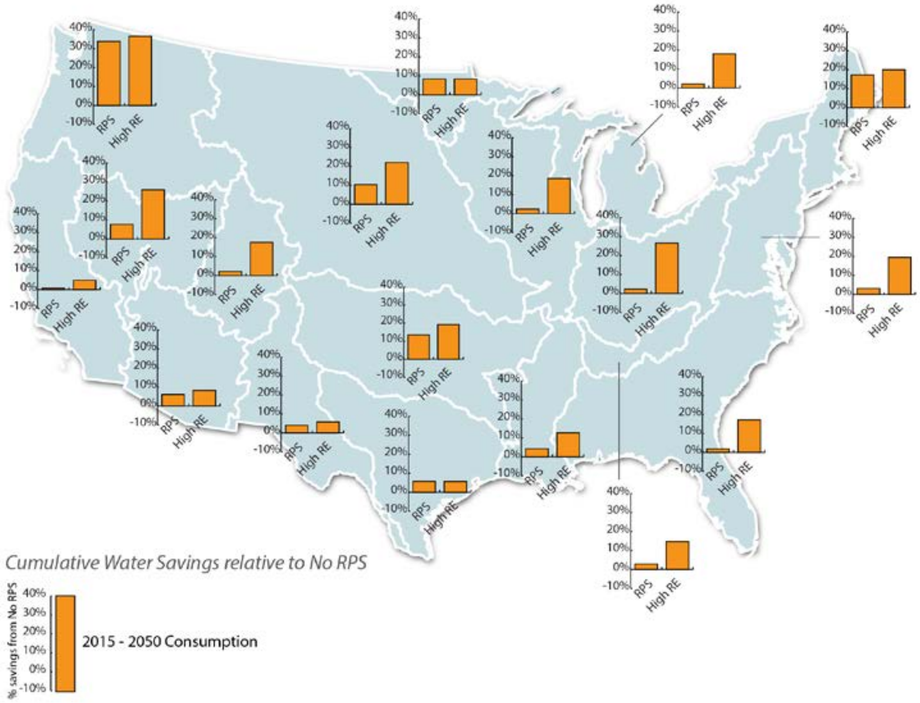
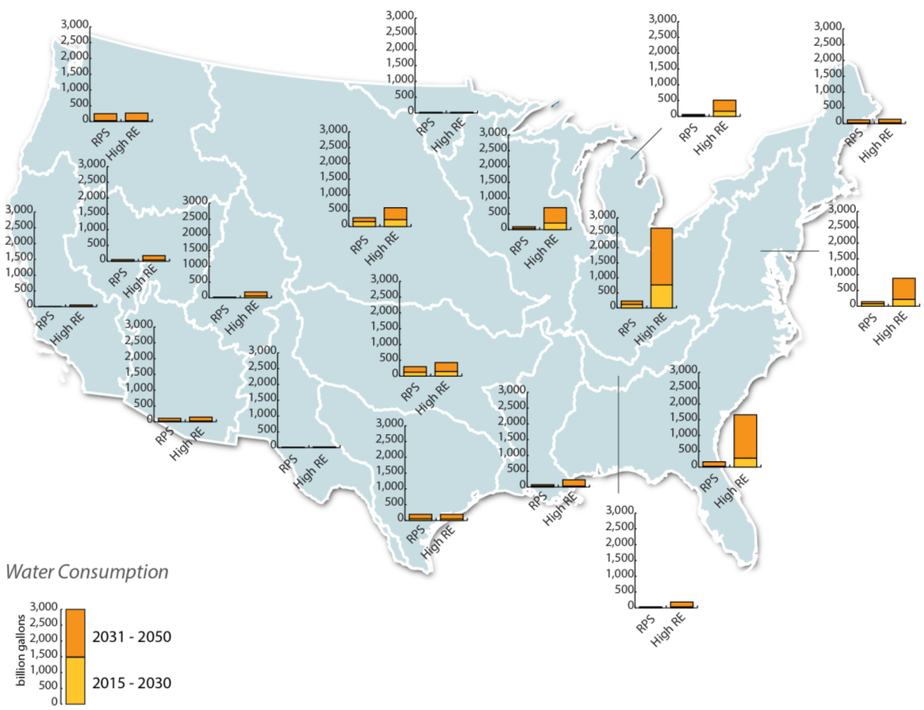


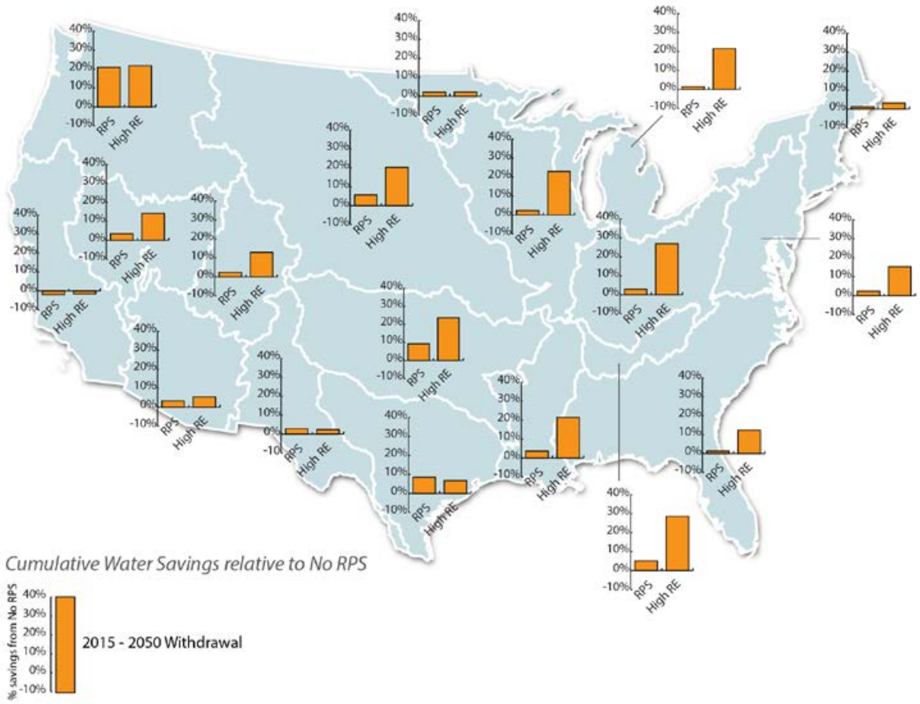
Figure 5.9. Electricity sector water (a) consumption and (b) withdrawal in three modeled scenarios

(a) Water Consumption (percent savings and gallon savings from No RPS scenario)





(b) Water Withdrawal (percent savings and gallon savings from No RPS scenario)



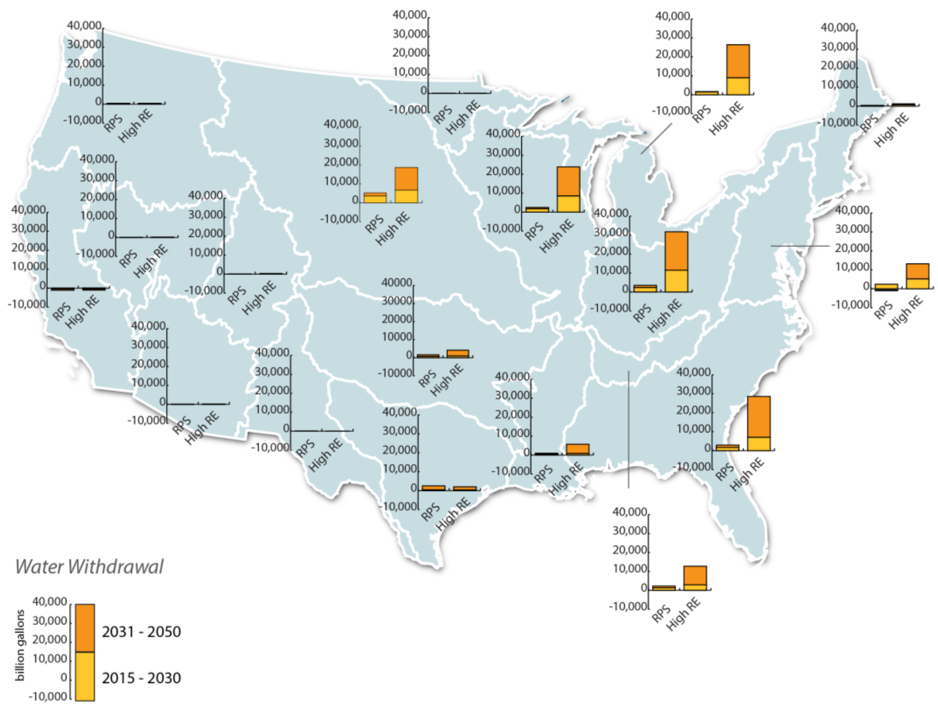


Figure 5.10. Regional water consumption (a) and withdrawal (b) savings relative to No RPS

6. Impacts of Existing RPS and Expanded RE

Using the methods discussed earlier, we evaluate two potential impacts associated with the Existing RPS and High RE scenario, both relative to the No RPS scenario:

- Gross RE workforce and economic development impacts
- Natural gas price reduction impacts.

We make no claim of net societal benefits for these two impacts. While individual states may benefit from an increase in gross RE jobs or reduced natural gas prices, on an international or national basis these impacts are most likely to represent resource transfers. Growth in RE workforce, for example, may come at the expense of job losses elsewhere in the economy, and though net job changes are possible we do not evaluate them here. And while natural gas price reductions will unambiguously benefit energy consumers, those benefits come at the expense of natural gas producers and those who benefit from natural gas production.

Gross Renewable Energy Workforce Requirement and Associated Economic Development Impacts

As a consequence of the greater amount of RE deployment, the Existing RPS and High RE scenarios drive increased gross domestic RE-related jobs relative to the No RPS baseline (Figure 6.1). In terms of total cumulative job-years over the entire 2015–2050 period, the Existing RPS scenario yields 4.7 million additional job-years compared to the No RPS scenario, a 19% increase in RE-related employment required. This is equivalent to the renewable energy sector needing approximately 134,000 more workers annually, on average, in comparison to the No RPS scenario. The High RE scenario, meanwhile, is estimated to require 11.5 million additional job-years, again relative to the No RPS baseline, a 47% boost. We do not estimate economy-wide net impacts, and the increased RE jobs noted here will be expected—at a national or international scale—to be partially or fully offset by job contraction in other parts of the economy.

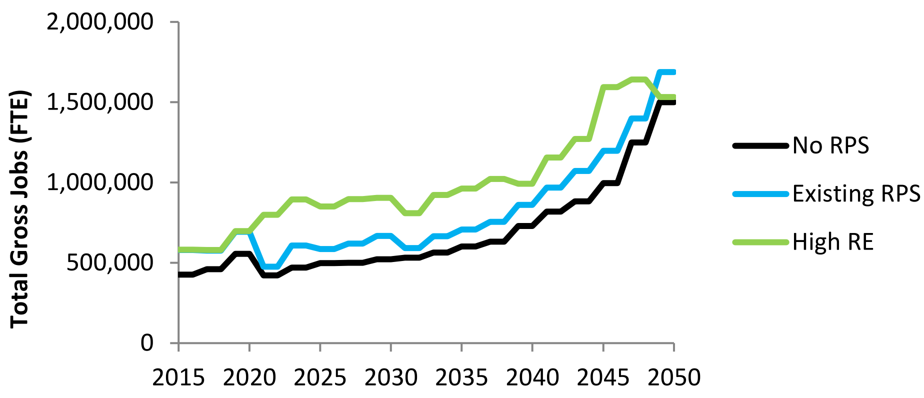


Figure 6.1. Gross domestic RE-related jobs in three modeled scenarios

Figure 6.2 illustrates the breakdown among these job totals by RE technology, by onsite vs. supply chain vs. induced, and by construction versus O&M.[55] The distribution of jobs among renewable technologies reflects both the contribution of each technology to generation and capacity, as well as the labor-intensity of their construction and operation phases. As shown, jobs related to solar PV—including both distributed and utility scale—dominate the totals in all three scenarios, followed by wind. Supply-chain job totals are somewhat larger than onsite and induced jobs in all three scenarios. In part, this reflects the fact that one-time construction jobs, which directly impact supply-chain totals, are somewhat greater in magnitude than ongoing RE O&M jobs.

[55] For each scenario, the total job-years are equal across all three breakdown categories shown in Figure 6.2 because all jobs are allocated to each subcategory. For example, "Solar" jobs include onsite, supply chain, and induced jobs that resulted from the construction and operations of new solar generation. Similarly, "Construction" jobs in this figure include onsite construction as well as supply chain (e.g., materials) needed for and induced jobs resulting from the construction activity.

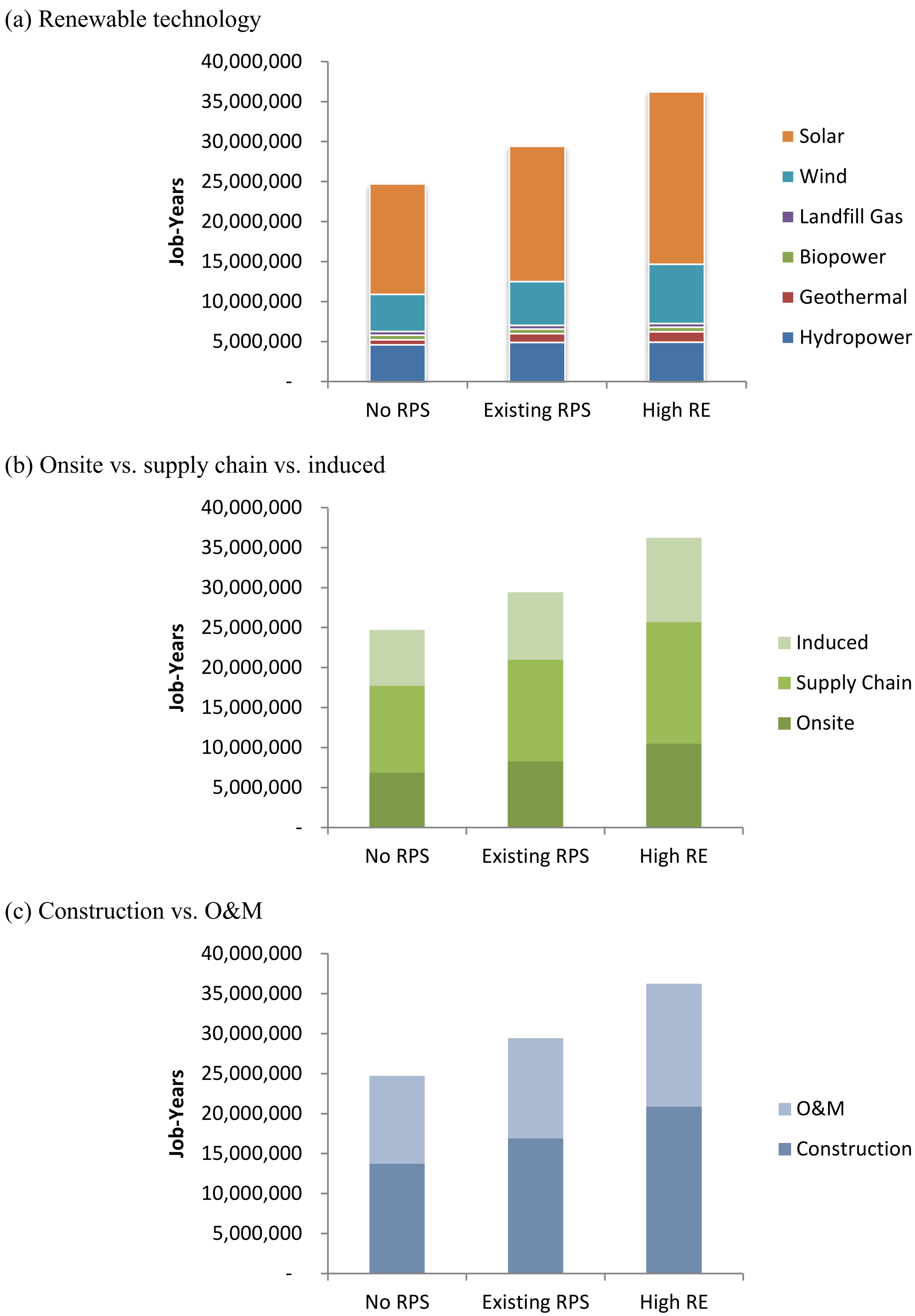


Figure 6.2. Total domestic RE-related job-years (2015–2050) by (a) renewable technology; (b) onsite, supply chain, and induced; and (c) construction and O&M

Of the three categories of jobs—onsite, supply chain, and induced—only onsite jobs can be readily linked to specific regions. The distribution of onsite jobs (including those associated with both construction and O&M) across regions under the Existing RPS and High RE scenarios relative to the No RPS baseline, largely corresponds to the distribution of incremental RE deployment (see Figure 6.3). In particular, the Existing RPS case yields the greatest number of incremental onsite jobs in the Pacific, Middle Atlantic, and New England Regions. The High RE case, on the other hand, yields the largest incremental onsite job increases in the South Atlantic region.[56]

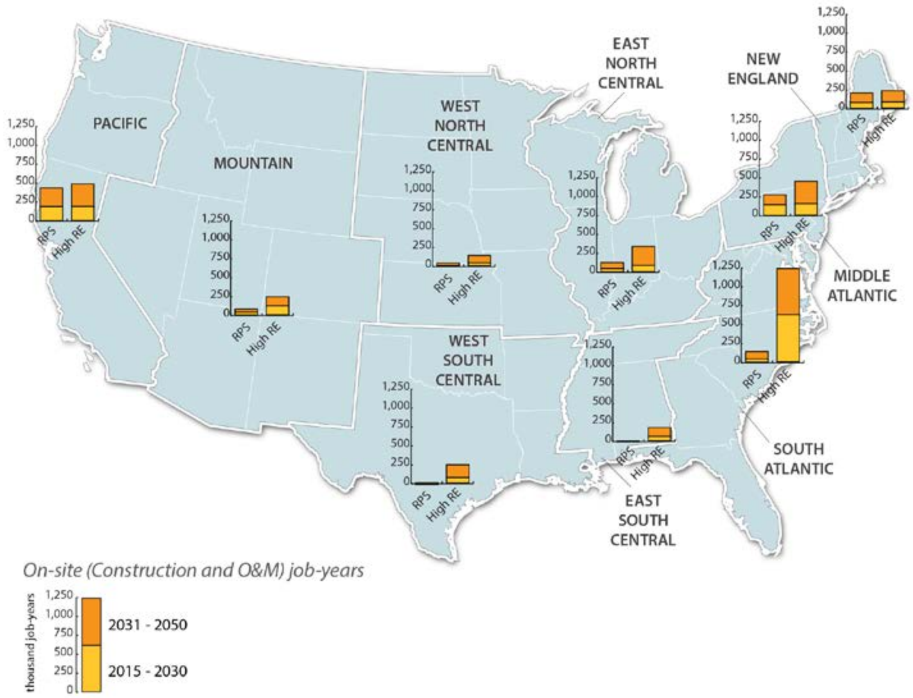


Figure 6.3. Regional gross onsite jobs relative to No RPS

Finally, Table 6.1 summarizes the results for earnings, output, and gross domestic product across the entire analysis time period for each of the three scenarios. The results largely mirror those presented above for employment effects. We again emphasize that these figures represent gross impacts associated with RE deployment and not net economy-wide effects.

Table 6.1. Gross Total (2015–2050) RE-Related Earnings, Output, and Gross Domestic Product in Three Modeled Scenarios

Gross Impact (2015$ million)	No RPS	Existing RPS	High RE
Earnings	1,281,000	1,562,000	1,962,000
Output	3,956,000	4,727,000	5,841,000
GDP	2,827,000	3,562,000	3,573,000

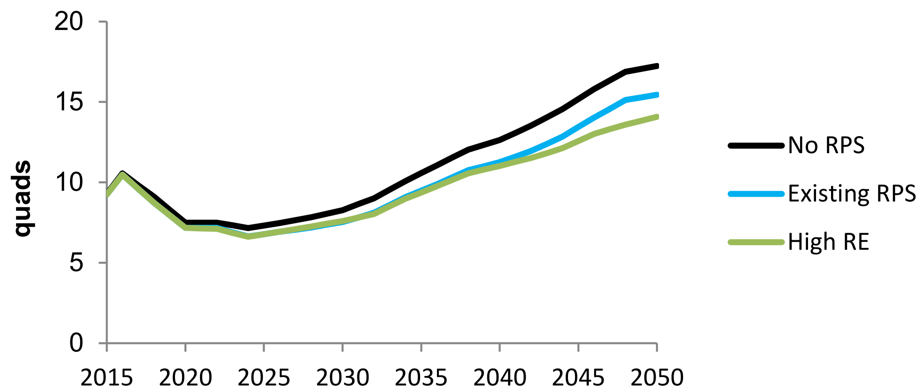
[56] RE employment is tied to both capacity expansion and the type of RE deployed. As shown in figure 6.2, some technologies require more workers for either installation or O&M. This is particularly true for solar PV installation, which is relatively more labor-intensive than other RE technologies.

Natural Gas Price Reduction Impacts

Achieving the Existing RPS and High RE scenarios reduces cumulative 2015–2050 electricity sector natural gas consumption by a total of 35 quads and 46 quads, respectively, relative to the No RPS baseline (Figure 6.4). These reductions represent 3.3% and 4.3% of total economy-wide natural gas consumption in the United States over the same time period. Despite the much-more aggressive RE deployment in the High RE scenario, natural gas demand reduction is only modestly higher than under the Existing RPS scenario due to the higher-degree of coal displacement under the High RE case.

These estimated economy-wide natural gas demand reductions place downward pressure on natural gas prices, illustrated on a national basis in Figure 6.4. Though the figure presents national average results, the price changes vary somewhat by region; regional reductions in 2050 of $0.36 to $0.59 per million Btu (MMBtu) are estimated in the Existing RPS scenario, whereas reductions of $0.69 to $0.89/MMBtu are estimated in the High RE scenario.

(a) Natural gas consumption



(b) Natural gas delivered prices

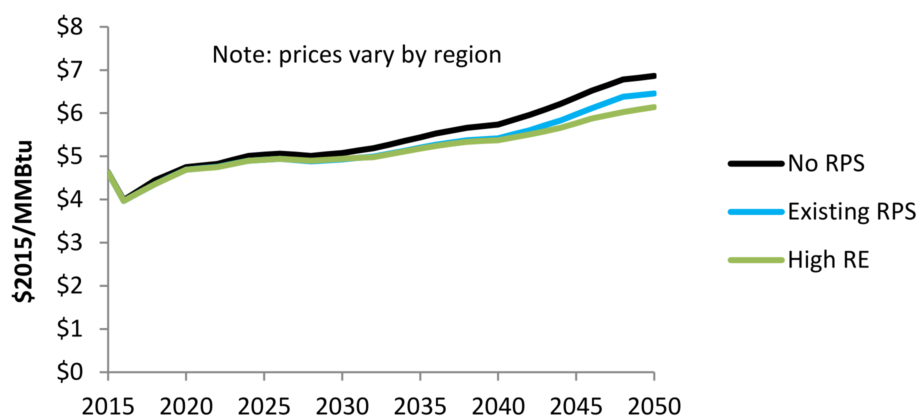


Figure 6.4. Electricity sector natural gas (a) consumption and (b) delivered prices in three modeled scenarios

These price changes, as they affect the electricity sector, are reflected in the results presented earlier on the cost and retail electricity price impacts of the various scenarios. In addition gas price reductions provide consumer benefits in the form of lower natural gas costs outside of the electricity sector. In particular, as shown in Figure 6.5, natural gas bill savings from the Existing RPS scenario total $78 billion on a discounted, present-value basis, which is equivalent to a levelized impact of RE of 1.9¢/kWh-RE. Under the

High RE scenario, total consumer savings equal $99 billion, or 0.9¢/kWh-RE. While absolute consumer savings are greater under the High RE scenario compared with the Existing RPS, levelized impacts are lower due to the greater amount of incremental RE in the former.

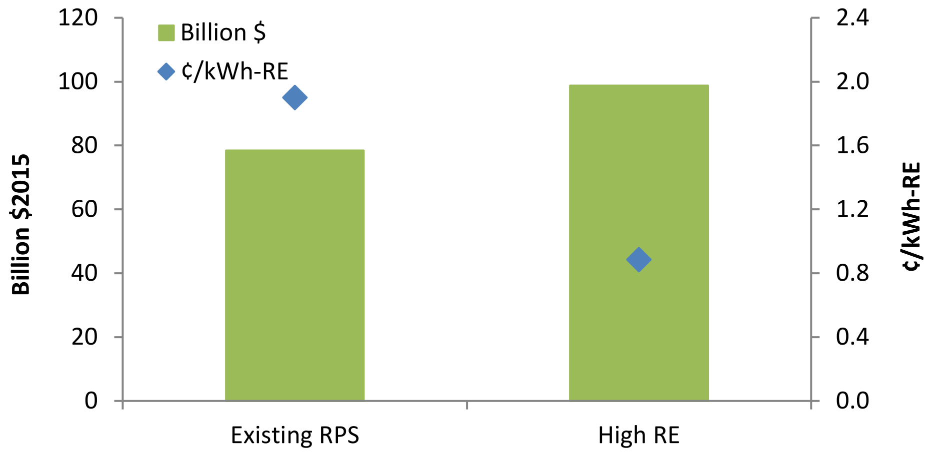


Figure 6.5. Present value (2015–2050) non-electric natural gas consumer savings relative to No RPS

Consumer benefits vary by region depending on the estimated regional gas price reduction and total regional non-electric natural gas consumption (Figure 6.6). Importantly, while individual regions or states may experience net benefits associated with these natural gas price changes, the potential price reductions and consumer savings are likely to be primarily, or even exclusively, *transfer payments* from gas producers (and those that benefit from gas production, such as owners of mineral rights) to gas consumers on a national basis.

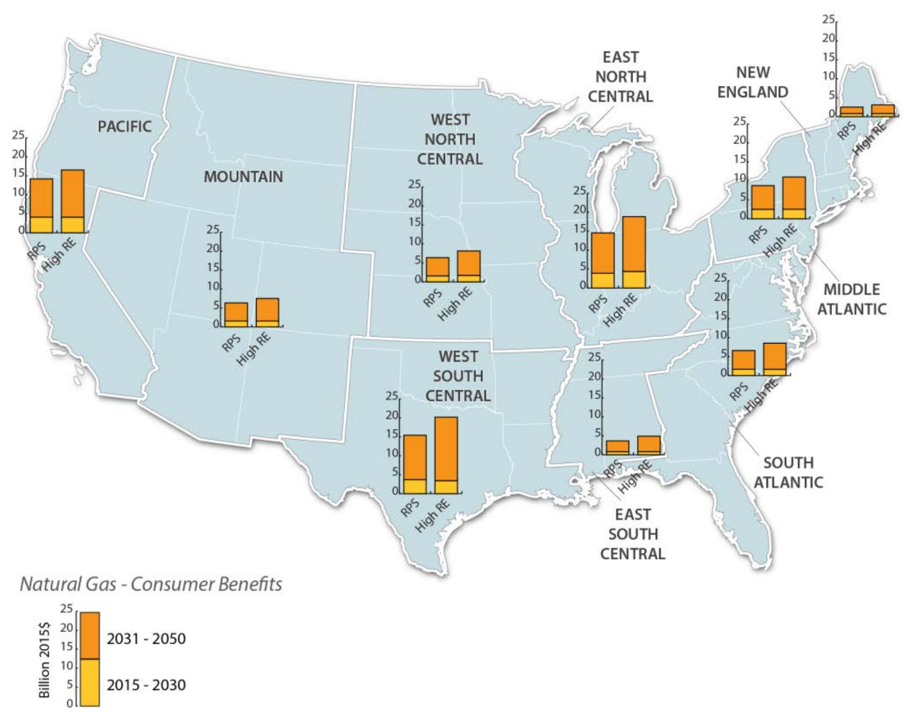


Figure 6.6. Regional (non-electric) natural gas consumer savings relative to No RPS

7. Summary and Conclusions

RPS policies have been a driver of growth in renewable capacity and generation in the past and, based on already established future-year policy targets, are expected to continue to require substantial new renewable capacity in coming years (Barbose 2016a). This analysis estimates the prospective benefits and costs associated with new renewables needed to meet future-year targets of existing RPS policies as well as those associated with higher renewable penetrations that could be achieved under an expanded RPS adoption scenario. Benefits are estimated based on changes in the generation mix and the resulting physical impacts calculated through 2050 using the ReEDS model, with monetary estimates applied as feasible. Costs include all electric infrastructure and operating costs and are estimated in terms of both the net present value of electric system expenditures as well as changes to average retail electricity prices.

Our analysis finds that the *Existing RPS* scenario will require 66 GW of renewables (218 TWh of incremental renewable generation) above the No RPS scenario by 2030 and 122 GW (296 TWh of renewable generation) by 2050. These values reflect the amount of incremental RE needed to satisfy RPS requirements beyond 2014 and serve as the basis for which we evaluate the costs, benefits, and impacts. The Existing RPS scenario results in 26% renewables (including hydropower) penetration by 2030 and 40% by 2050, compared to 21% and 34%, respectively, under the No RPS scenario. Wind and solar dominate capacity additions, but significant incremental generation is also derived from biomass and geothermal resources. The new RE generation largely offsets fossil generation, with a greater amount of coal offset before 2030, but more natural gas offset in the longer term. RE used to meet existing RPS requirements from 2015 to 2050 results in cumulative emissions reductions equal to 2.1 million metric tons of SO_2 (5.5% as a percentage of total electricity sector emissions), 2.5 million metric tons of NO_x (5.7%), and 0.3 million metric tons of $PM_{2.5}$ (4.5%). Based on these reductions, total health and environmental benefits are estimated to be $97 billion (central estimate), or 2.4¢/kWh-RE. In addition, the generation mix in the Existing RPS scenario results in cumulative GHG savings from 2015 to 2050 equal to 4.7 billion metric tons of CO_2-equivalent, or 6% of total life-cycle emissions from the electricity sector. Under the central estimate, global climate damage reductions equal $161 billion on a discounted, present value basis, or 3.9¢/kWh-RE.

The *High RE scenario* results in substantial additional capacity of 215 GW of renewables above the baseline No RPS scenario by 2030 (or 627 TWh of incremental renewable generation) and 331 GW of incremental renewables (or 765 TWh of generation) by 2050. This translates to an RE penetration of 35% by 2030 and 49% by 2050. Again, wind and solar are the dominant RE technologies deployed. Coal is the dominant form of avoided generation in the High RE scenario, even more so than under the Existing RPS scenario. The High RE scenario leads to cumulative (2015–2050) air emission savings of 11.1 (29%), 12.8 (29%), and 1.8 (29%) million metric tons of SO_2, NO_x, and $PM_{2.5}$, respectively. The health benefits of these reduced emissions are estimated to be $558 billion on a present-value basis (central estimate), or 5.0¢/kWh-RE. In addition, under the High RE scenario, GHG savings equal 18.1 billion metric tons, equivalent to 23% of total life-cycle emission in the electricity sector from 2015 to 2050. Using central estimates, present-value global climate damage reductions from the High RE scenario equal $599 billion, equivalent to a levelized benefit of 5.4¢/kWh-RE.

In addition to the air and health benefits and GHG savings, the Existing RPS and High RE scenarios also yield benefits or impacts in the form of reduced water consumption and withdrawals, increased renewable energy-related employment, and reductions in natural gas demand that lower consumer gas bills. Relative to the No RPS baseline, total water consumption in the electricity sector from 2015–2050 is 4% and 18% lower under the Existing RPS and High RE scenarios, respectively. The scenarios also require an increase in gross domestic RE-related jobs, although these could lead to offsets by job contraction in other parts of the economy. Over the entire 2015–2050 period, the Existing RPS scenario requires 4.7 million additional cumulative job-years, a 19% increase in RE-related employment, while the High RE scenario requires 11.5

million additional job-years, a 47% boost. Gross onsite jobs, which include construction and O&M jobs, represent 28% and 29% of all gross jobs, respectively, in the Existing RPS and High RE scenarios. Finally, achieving the Existing RPS and High RE scenarios reduces cumulative 2015–2050 electricity sector natural gas demand by 35 quads and 46 quads, respectively, relative to the baseline. Gas price reductions that result from reduced consumption provide consumer benefits in the form of lower natural gas bills, with bill savings from the Existing RPS scenario totaling $78 billion on a discounted, present-value basis, or 1.9¢/kWh-RE. Under the High RE scenario, total consumer savings equal $99 billion, or 0.9¢/kWh-RE.

In comparison to the benefits, incremental system cost impacts are 1.5¢/kWh-RE or less in both scenarios. Figure 7.1 shows a comparison of the incremental system cost impacts relative to RPS benefits that can be monetized. Estimated costs include all electric infrastructure and operating costs and are evaluated under a range of sensitivity cases related to natural gas prices and RE costs. For the Existing RPS scenario, incremental system costs are estimated to range from ±$31 billion (-0.7% to 0.8%). On a levelized basis, these costs are estimated to be about ±0.75¢/kWh-RE. On the low end of the ranges, incremental costs are found to be negative, suggesting that the RE used to meet aggregate existing RPS policies is economically competitive with other generation sources, when high natural gas prices are assumed. On the other hand, higher RE costs or lower natural gas prices can result in positive compliance costs. In either case, our scenarios suggest likely small national-level electric system cost impacts in either direction for the Existing RPS scenarios. For the Existing RPS scenario, we find incremental retail electricity prices of up to about 1¢/kWh on the high end and reduced prices on the low end.

For the High RE scenario, we find a larger range of incremental costs, ranging from $23 billion (0.6% of total system costs) to $194 billion (4.5% of total system costs), which is equivalent to 0.26¢/kWh-RE to 1.5¢/kWh-RE on a levelized basis. All of the sensitivities conducted for the High RE scenario were found to have greater system costs than the No RPS scenario, with the highest incremental costs found when high RE technology costs are assumed. The range of incremental electricity prices is greater for the High RE scenario compared to the Existing RPS scenario, particularly after 2020. On the high end of the range, regional incremental prices are estimated to peak at as much as 4.2¢/kWh and average (for all years) about 2.9¢/kWh. The low end of the range of incremental prices for the High RE scenario is similar to that for the Existing RPS scenario.

Summarizing the comparison, we find that the benefits exceed the costs, even when considering the highest cost and lowest benefit outcomes (Figure 7.1). Under the Existing RPS scenario, the high end costs are 0.75¢/kWh-RE, while air pollution and health benefits total at least 1.2¢/kWh-RE and GHG benefits total at least 0.9¢/kWh-RE. Under the High RE scenario, the high end costs are 1.5¢/kWh-RE while air pollution and health benefits total at least 2.7¢/kWh-RE and GHG benefits total at least 1.2¢/kWh-RE. The figures here are presented on a national basis.

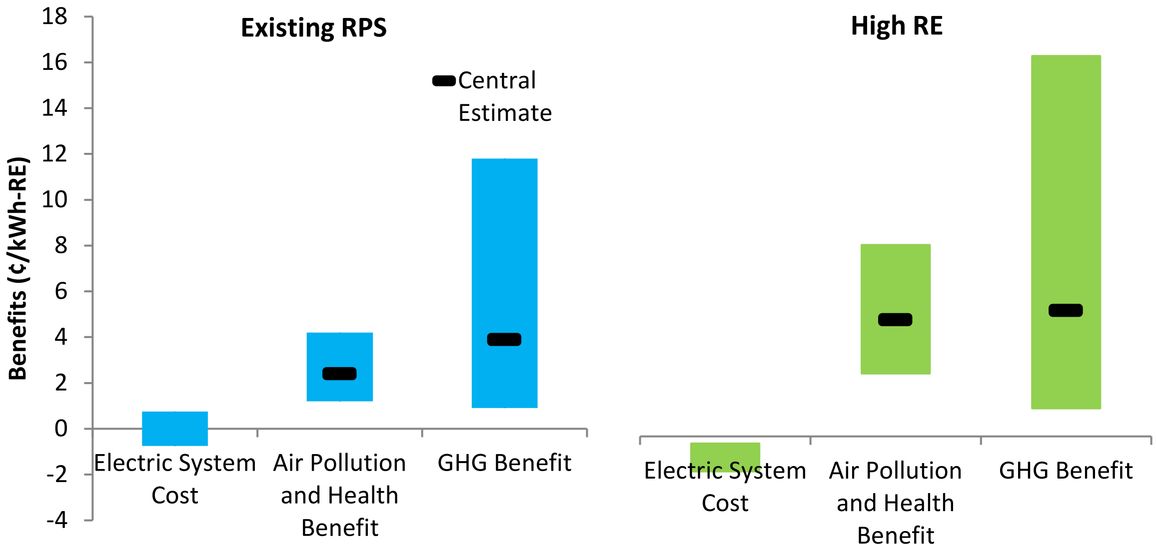


Figure 7.1. Comparison of national systems costs and monetized benefits under the Existing RPS and High RE scenarios

Note: Positive values reflect benefits in the Existing RPS and High RE scenarios, whereas negative values reflect higher costs relative to the No RPS scenario. Water benefits, gross RE workforce and economic impacts, and natural gas impacts are not shown here.

While we did not evaluate state RPS policies individually, national and regional results can help policymakers understand regional trends and inform state-level decisions about policy changes. Under the Existing RPS scenario, the Pacific region in particular shows considerable (relative to other regions) incremental renewable generation in both the near and longer term. Other regions with lesser, but still substantial, incremental renewable generation under the Existing RPS scenario relative to the No RPS scenario, particularly by 2050, include the East North Central, Middle Atlantic, New England, and Mountain regions. Notably, the significant RPS required renewable generation in New England and the Pacific region largely offset gas while smaller amounts of incremental renewables elsewhere help reduce more coal. In general, there is a more uniform regional distribution of incremental renewable generation in the High RE scenario and greater reduction in coal usage as a result of the construction of the scenario.

Our analysis has several limitations. First, we recognize that there may be more cost-effective ways to achieve the benefits and impacts discussed in this paper. Second, while our analysis examines the costs, benefits, and impacts of RE needed to meet RPS requirements going forward, it does not seek to *attribute* those effects solely to RPS policies. Third, our work distinguishes between the potential benefits and impacts of RPS programs. Impacts are best considered as resource transfers, benefiting some stakeholders at the expense of others, although such impacts might still be relevant considerations when evaluating state RPS programs. We do not evaluate the *net* effects of these impacts over the entire country and thus cannot assess whether or not these impacts reflect net costs or benefits at a national scale. Fourth, we consider the impacts of RE needed to meet all existing (and expanded) RPS in aggregate and do not estimate the impacts of any individual RPS policy. Finally, our analysis considers an important subset of, although not all, potential benefits and impacts; for example, we do not quantify land use and wildlife impacts. Despite these limitations, the analysis can inform decision makers about the prospective costs, merits, and value of state RPS programs as they consider revisions to existing policies and development of new policies.

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