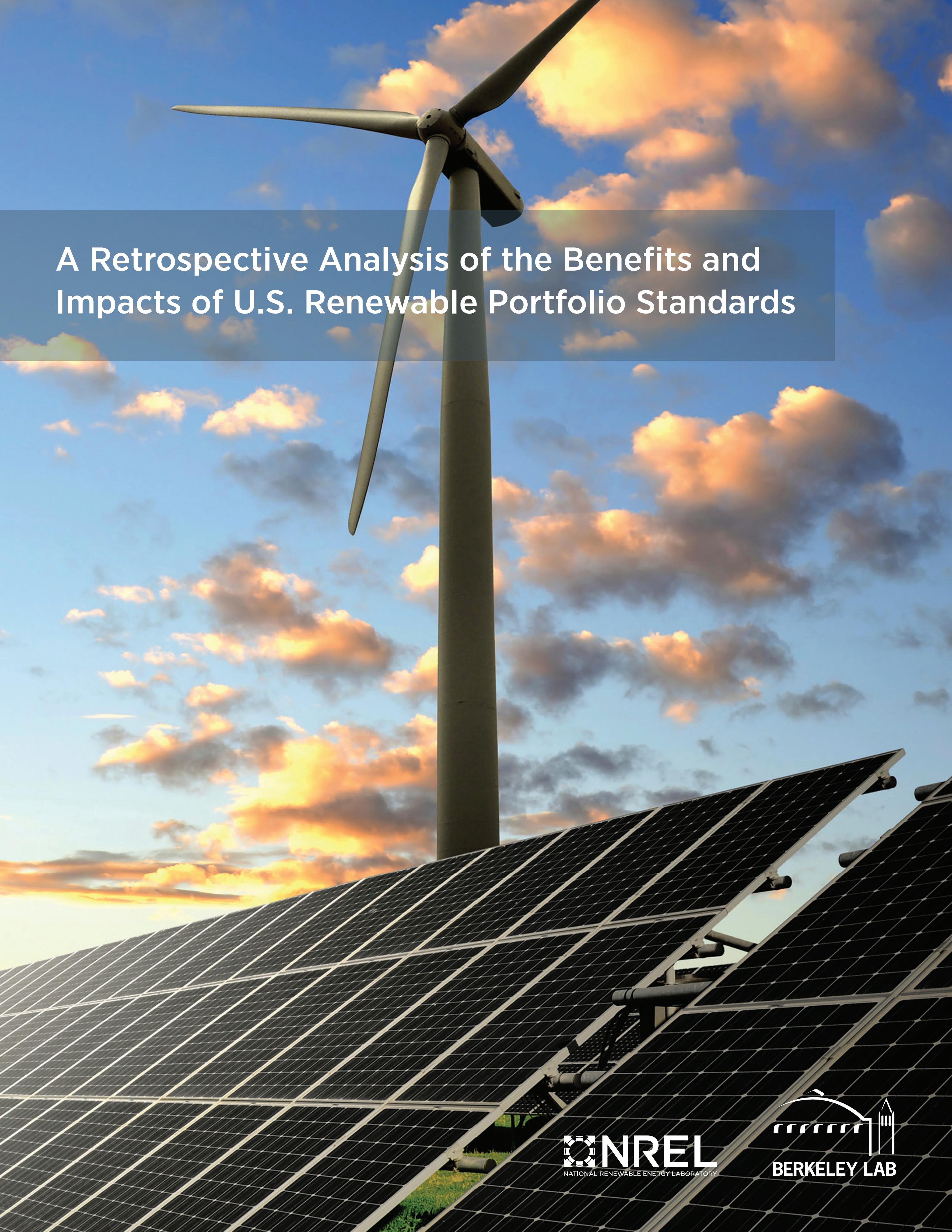
A Retrospective Analysis of the Benefits and Impacts of U.S. Renewable Portfolio Standards



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A Retrospective Analysis of the Benefits and Impacts of U.S. Renewable Portfolio Standards

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Technical Report
TP-6A20-65005
LBNL-1003961
January 2016

Contract Nos. DE-AC36-08GO28308 (NREL) and DE-AC02-05CH11231 (LBNL)

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Please cite as follows:
Wiser, R., G. Barbose, J. Heeter, T. Mai, L. Bird, M. Bolinger, A. Carpenter, G. Heath, D. Keyser, J. Macknick, A. Mills, and D. Millstein. 2016. *A Retrospective Analysis of the Benefits and Impacts of U.S. Renewable Portfolio Standards.* Lawrence Berkeley National Laboratory and National Renewable Energy Laboratory. NREL/TP-6A20-65005. http://www.nrel.gov/docs/fy16osti/65005.pdf.

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 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. In particular, this analysis series evaluates RPS programs in terms of the following:

- **RPS compliance costs** represent the incremental cost of meeting RPS compliance obligations, 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. RPS compliance costs may be negative, if the renewable electricity used for RPS compliance is less expensive to the utility than the alternatives.
- **Benefits**, as analyzed in this report series, consist specifically of environmental 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.
- **Other impacts**, in the form of resource transfers from one market participant or segment to another, are also evaluated. These other 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 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 the present study.

This report, the second in the series, analyzes historical benefits and impacts of 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: greenhouse gas emissions, air pollution, 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. These benefits and impacts are also subject to many uncertainties, which are described and, to the extent possible, quantified within the report.

The present report is intended to help policymakers, RPS administrators, and other decision-makers gauge the potential significance of a number of key benefits and impacts from state RPS programs. By noting limitations, caveats, and uncertainties in these results, the report also seeks to highlight important methodological considerations to evaluating RPS benefits and impacts. This report does not, however, provide a complete picture, and comparable information on both the costs and benefits, as well as other impacts, are ultimately needed to inform decision-making. To that end, a third report in this series is planned for the coming year to evaluate the future costs, benefits, and other impacts of state RPS policies, under both current policies and possible revisions.

Acknowledgments

The authors would like to thank the U.S. Department of Energy's (DOE) Office of Energy Efficiency and Renewable Energy's (EERE) Strategic Programs Office for primary funding support for this analysis. In particular, the authors are grateful to Steve Capanna of the Strategic Programs Office for his support of this project.

The authors would also like to thank the following individuals for their thoughtful review: Doug Arent, Joint Institute for Strategic Energy Analysis; Howard Bernstein, Massachusetts Department of Energy Resources; Kevin DeGroat, Antares Group; Jeff Deyette, Union of Concerned Scientists; Warren Leon, Clean Energy Group; Tom Stanton, National Regulatory Research Institute; Jaquelin Cochran, Jeffrey Logan, David Mooney, and Robin Newmark of the National Renewable Energy Laboratory (NREL); and Caitlin Callaghan, Steve Capanna, Eric Hsieh, and Lawrence Mansueti of DOE. We also wish to thank Karin Haas of NREL for editorial support, Jenny Melius of NREL for GIS support, and Stuart Cohen for research support.

ACRONYMS

AVERT	AVoided Emissions and geneRation Tool
Btu	British thermal unit
CAIR	Clean Air Interstate Rule
CCGT	combined cycle gas turbine
CO_2	carbon dioxide
CO_2e	carbon dioxide-equivalent
CPP	Clean Power Plan
CSP	concentrating solar power
CT	combustion turbine
DOE	U.S. Department of Energy
EIA	U.S. Energy Information Administration
EMW	Great Lakes/Mid-Atlantic region
EPA	U.S. Environmental Protection Agency
FTE	full-time equivalent
GDP	gross domestic product
GHG	greenhouse gas
I-O model	input-output model
IWG	Interagency Working Group
JEDI	Jobs and Economic Development Impacts model
kW	kilowatt
kWh	kilowatt-hour
LBNL	Lawrence Berkeley National Laboratory
LFG	landfill gas
LSE	load-serving entity
MW	megawatt
MWh	megawatt-hour
NEMS	National Energy Modeling System
NO_x	nitrogen oxides
NREL	National Renewable Energy Laboratory
O&M	operations and maintenance
PM	particulate matter
PV	photovoltaic
RE	renewable energy
REC	renewable energy certificate
RPS	renewable portfolio standard
RTO	regional transmission organization
SCC	social cost of carbon
SO_2	sulfur dioxide
TW	terawatt
TWh	terawatt-hour
VSL	value of statistical life
W	watt

Executive Summary

State renewable portfolio standards (RPS) currently exist in 29 states and Washington, D.C. Most of these policies, enacted largely during the late 1990s and 2000s, will reach their terminal targets within the next decade. As states consider extending, eliminating, or otherwise revising existing RPS programs, or developing new ones, increasing attention is being paid to the costs, benefits, and other impacts of these policies.

A prior study (Heeter et al. 2014) and subsequent update (Barbose et al. 2015) in this report series found that RPS compliance costs over the 2010–2013 period were generally equivalent to less than 2% of average statewide retail electricity rates, but varied substantially, with the net cost to utilities and other load-serving entities ranging from -0.4 to 4.8¢ per kilowatt-hour of renewable electricity (kWh-RE).[1] In aggregate, total RPS compliance costs represented approximately $1 billion per year, on average, over the 2010–2013 period. The prior study also summarized RPS benefits studies published by individual state regulatory agencies; however, the small number of such studies, and their widely varying methods and scopes, ultimately limited any comparisons across states or generalization beyond the specific studies performed. This dearth of comparable analyses prompted the need for a broader evaluation of RPS program benefits and impacts, relying on a standardized methodology and scope.

The present report follows directly from the preceding study, and is intended to provide the first national-level assessment of the potential benefits and impacts of state RPS programs, using an established and uniform set of methodologies and robust data sets. The analysis focuses specifically on "new" renewable electricity (RE) resources built after RPS enactment and used to meet RPS compliance obligations in 2013—the most recent year for which the necessary data were available. Based on data compiled from regulatory filings and other sources, 98 terawatt-hours (TWh) of new RE generation was used to meet RPS obligations in 2013, representing 2.4% of total U.S. electricity generation in that year. Over the course of 2013–2014, an average of roughly 5,600 megawatts (MW) per year of new RE capacity was built to service RPS requirements.[2]

Using EPA's Avoided Emissions and geneRation Tool (AVERT) model to estimate displaced fossil generation, we estimate that new RE used for RPS compliance in 2013 resulted in a 3.6% reduction in total fossil fuel generation. Based on outputs estimated with AVERT and several additional analysis tools, we evaluate potential societal benefits associated with reductions in greenhouse gas (GHG) emissions, air pollution emissions, and water use. We also assess the impacts—describing below the distinction between "impacts" and "benefits"—of state RPS policies on gross jobs and economic development, wholesale electricity prices, and natural gas prices. These benefits and impacts are quantified in both physical and monetary terms where possible. We focus on the aggregate benefits and impacts of all state RPS compliance obligations, presenting results nationally and, where data and methods allow, by region and state; we do not, however, analyze the effects of individual state RPS programs.

Based on the methods described in the full report, new RE resources used to meet RPS compliance obligations in 2013 yielded the following benefits (summarized also in Figure ES-1):

- **GHG Emissions and Climate Change Damage Reductions:** Life-cycle GHG emissions were reduced by 59 million metric tons of carbon dioxide-equivalent (CO_2e) in 2013, which translates

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[1] RPS compliance costs represent the incremental cost to the utility or other load-serving entity with RPS obligations, *net* of avoided conventional generation costs. Negative RPS compliance costs may occur when renewable electricity procured to meet RPS obligations is less expensive than avoided conventional generation.

[2] For the purpose of capacity additions, we focus on the average over the 2013 through 2014 time period, because some portion of capacity additions completed in 2014 were under construction in 2013; averaging capacity additions over a multi-year period also smooths out some of the volatility in annual renewable capacity build rates.

into \$2.2 billion of global benefits when applying a "central value" (\$37/metric ton of CO_2) for the social cost of carbon. These global benefits are equivalent to 2.2¢ per kilowatt-hour (kWh) of new RE (kWh-RE) used to meet 2013 RPS compliance. Benefits estimates span \$0.7 billion to \$6.3 billion (0.7 to 6.4¢/kWh-RE) across the full range of social cost of carbon estimates considered.

- **Air Pollution Emissions and Human Health and Environmental Benefits:** National emissions of sulfur dioxide (SO_2), nitrogen oxides (NO_x), and particulate matter 2.5 ($PM_{2.5}$) were reduced by 77,400, 43,900, and 4,800 metric tons in 2013, respectively. We estimate that these reductions—using a range of approaches—produced health and environmental benefits equal to \$5.2 billion, on average. These benefits are equivalent to 5.3¢/kWh of new RE used for 2013 RPS compliance. Across the full range of approaches considered, health and environmental benefits span \$2.6 billion to \$9.9 billion (2.6 to 10.1¢/kWh-RE). The largest health benefits accrue to the eastern half of the country, especially in the Mid-Atlantic, Great Lakes, Northeast, and Texas.
- **Water Use Reduction:** National water withdrawals and consumption in 2013 were reduced by 830 billion gallons and 27 billion gallons, respectively, equivalent to savings of 8,420 gallons of withdrawal and 270 gallons of consumption per megawatt-hour (MWh) of new RE used for 2013 RPS compliance.[3] These reductions amount to 2% of both total 2013 power sector water withdrawals and consumption. Water use reductions vary seasonally and come predominantly from freshwater sources, with reductions varying regionally due to geographic differences in power plant fuel types and cooling system configurations. The largest withdrawal and consumption reductions were in California and Texas, respectively, demonstrating the benefits RPS policies can have in water-stressed regions.

In addition to the set of societal benefits described above, we estimate three other impacts associated with new RE used to meet RPS compliance obligations in 2013. We distinguish these impacts from societal costs and benefits, because the direction of impact (positive or negative) varies by market participant. These impacts might thus best be considered resource transfers, and the present study does not assess their net, economy-wide effects. Given that context, we estimate that new RE resources used to meet RPS compliance obligations in 2013 produced the following impacts:

- **Gross Jobs and Economic Development:** Renewable generation used to meet 2013 RPS compliance obligations, along with average annual RPS-related capacity additions in 2013 and 2014, supported nearly 200,000 U.S.-based gross jobs in 2013 and drove over \$20 billion in gross domestic product (GDP), primarily based on NREL's Jobs and Economic Development Impacts (JEDI) suite of models. More than 30,000 of these gross domestic jobs are related to ongoing operations and maintenance (O&M), while 170,000 gross jobs are related to construction activity. Solar photovoltaic (PV) installations account for the majority of construction jobs, while established wind plants account for the majority of O&M jobs. California had the most significant renewable capacity expansion and generation associated with RPS compliance obligations, and thus had more of the associated onsite RE jobs than any other state.
- **Wholesale Electricity Price Reductions:** Renewable generation used to meet 2013 RPS compliance obligations potentially shifted the supply curve for electric power, reducing wholesale electricity prices and yielding an estimated \$0.0 to \$1.2 billion in savings to electricity consumers across the United States. These consumer savings are equivalent to 0.0 to 1.2¢/kWh of new RE used to meet 2013 RPS compliance. The wide range of estimates reflects bounding assumptions

[3] 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.

about how the effects of renewable generation on wholesale spot market prices decline over time and the extent to which consumers are exposed to those prices.

- **Natural Gas Price Reductions:** Renewable generation used to meet 2013 RPS compliance obligations reduced natural gas demand by an estimated 0.42 quads (422 million MMBtu). This reduction lowered average natural gas prices by an estimated 5¢ to 14¢/MMBtu in 2013, resulting in consumer savings ranging from $1.3 billion to $3.7 billion. These consumer savings are equivalent to 1.3¢ to 3.7¢/kWh of new RE used to meet 2013 RPS compliance. The range in estimates reflects bounding assumptions about when RPS-induced reductions in natural gas demand begin to affect prices.

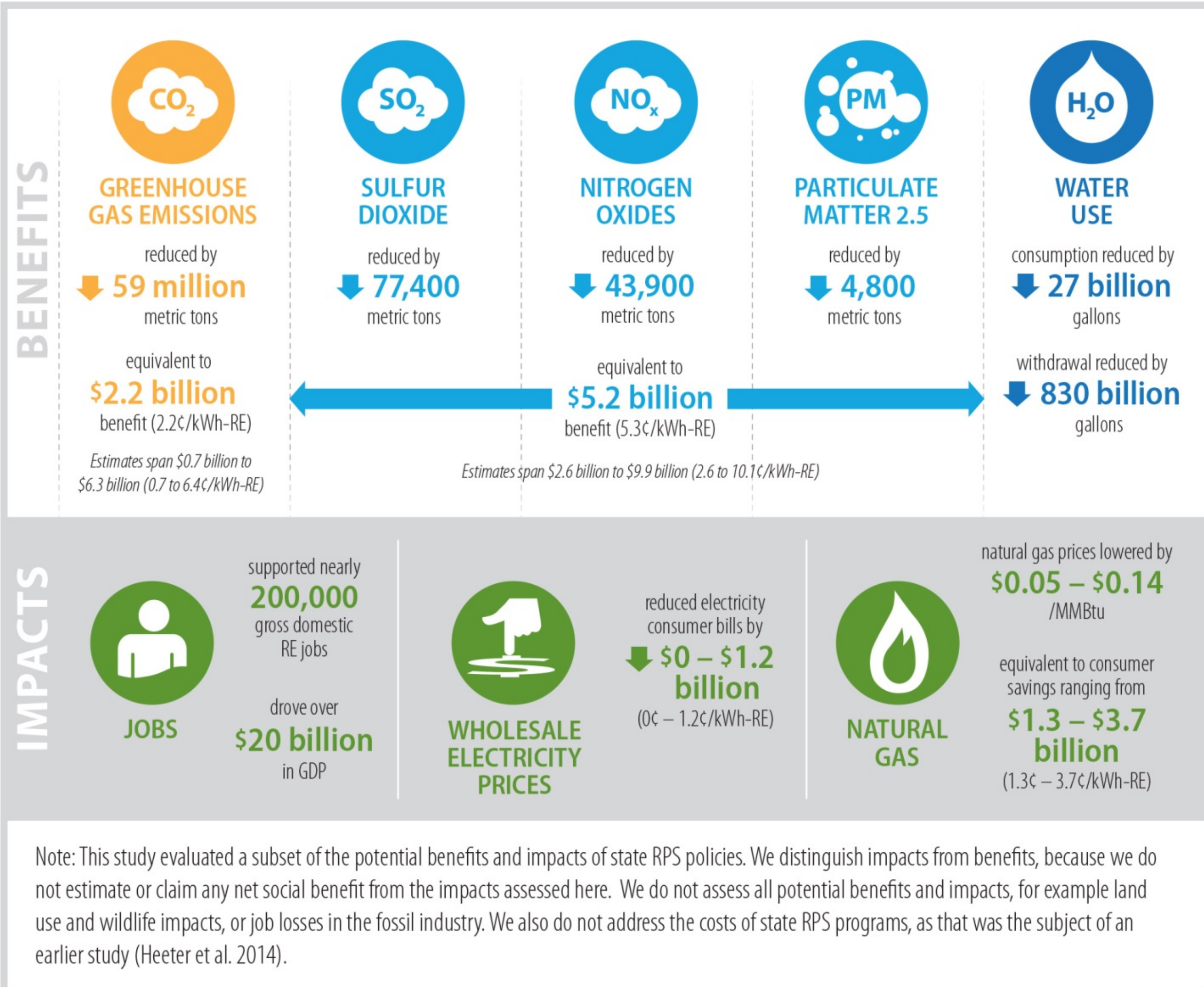


Figure ES-1. Benefits and impacts of new RE used to meet 2013 RPS compliance

Our analysis includes a number of limitations and caveats. First, it relies on a common set of standardized methods applied to all states, but individual states may have used or could use more-refined approaches, for example, more advanced modeling tools could be used to more precisely estimate wholesale market price suppression impacts. Second, while we use consistent methods and robust data sets, our assessments rely on models and methodologies that are sensitive to multiple parameters; accordingly, we qualify the study results where appropriate and highlight sources of uncertainty not explicitly quantified. Third, our work distinguishes between the potential benefits and impacts of RPS programs. As noted previously, impacts are best considered resource transfers, benefiting some stakeholders at a cost to others, though such impacts might still be relevant to evaluating state RPS programs. Fourth, 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. Fifth, this analysis does not formally compare the benefits and impacts of RPS programs to their costs. Although prior analysis (Heeter et al. 2014) focused specifically on RPS compliance costs, additional research is ultimately needed to evaluate the full set of RPS costs on a consistent basis across states, and to appropriately compare costs to benefits. Sixth, we have not evaluated whether RPS policies are the least-cost approach to achieving the benefits and impacts assessed. Lastly, our analysis does not seek to attribute the estimated benefits and impacts *solely* to RPS policies, given the multiple drivers of RE additions. Despite these limitations, the analysis can help inform decision makers of the value of state RPS programs and the scale of various potential benefits and impacts. In addition, the methodology used in the analysis provides a framework that states and analysts can build upon and refine for their own assessments.

Table of Contents

List of Figures

1. Introduction

Background

State renewable portfolio standards (RPS), which require electricity load-serving entities (LSEs) to meet a growing 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). They have been one of the policy drivers for RE growth in the United States, along with federal tax incentives and other forms of state-level support (Leon 2015). Collectively, 58% of all non-hydroelectric RE capacity built in the United States from 1998 through 2014 is being used to meet RPS requirements (Barbose 2015). In aggregate, existing state RPS policies require that by 2025, at which point most RPS requirements will have reached their maximum percentage targets, at least 8% of total U.S. generation supply will be met with RPS-eligible forms of renewable electricity, equivalent to roughly 106 gigawatts (GW) of renewable generation capacity (Wiser and Bolinger 2015).

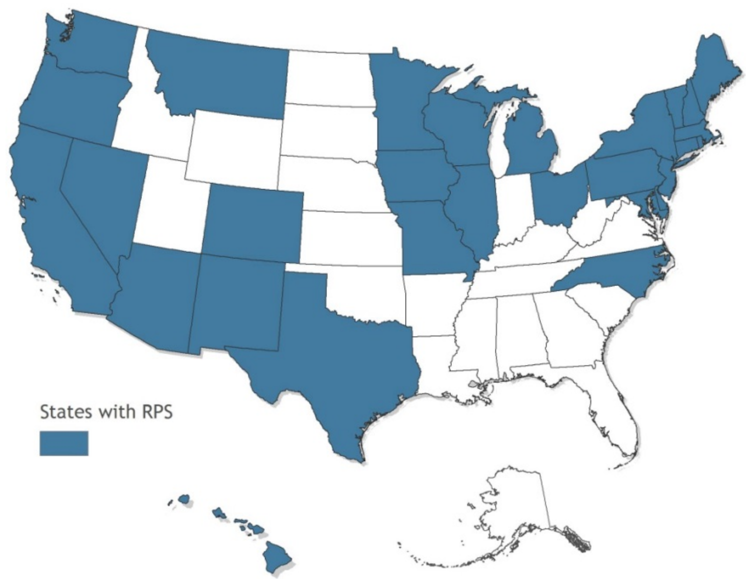


Figure 1.1. States with RPS policies circa November 2015

Many of these policies, which were enacted primarily during the late-1990s and 2000s, will reach their terminal targets within the next decade. As states consider extending, eliminating, or otherwise revising their RPS programs, or developing new ones, increasing attention is being paid to RPS costs, benefits, and other impacts. Previous work by Lawrence Berkeley National Laboratory and the National Renewable Energy Laboratory summarized RPS compliance costs retrospectively, drawing partly from estimates developed by utilities and state regulatory agencies in the context of annual compliance filings or periodic reports to state legislatures (Heeter et al. 2014; Barbose et al. 2015). That work found that RPS compliance costs over the 2010–2013 period were generally equivalent to less than 2% of average statewide retail electricity rates, but varied substantially, with the net cost to utilities and other load-serving entities ranging from -0.4 to 4.8¢ per kilowatt-hour of renewable electricity (kWh-RE).[4] In aggregate, total RPS compliance costs represented approximately $1 billion per year, on average, over the 2010–2013 period.

[4] RPS compliance costs represent the incremental cost to the utility or other load-serving entity with RPS obligations, *net* of avoided conventional generation costs. Negative RPS compliance costs may occur when renewable electricity procured to meet RPS obligations is less expensive than avoided conventional generation.

Compared to RPS compliance cost estimates, analyses of the potential broader societal benefits and impacts of RPS policies are relatively few and far between, and vary considerably in scope and methods (Heeter et al. 2014). This dearth of comparable RPS benefits analyses ultimately prevents policymakers from being able to comprehensively evaluate the merits of RPS policies, and has prompted the need for further analysis of the benefits and impacts of RPS programs, based on a consistent approach across states.

Scope, Methods, and Contribution

The present work is part of an ongoing series of analyses that collectively seek to assess the costs, benefits, and other impacts of state RPS programs. In this analysis, we apply a well-vetted set of methods to quantify a number of broad potential societal benefits and impacts of state RPS compliance. We use established methodologies that draw heavily from the existing literature and build on the approaches used in the U.S. Department of Energy (DOE)'s *Wind Vision Report* (DOE 2015). The analysis is retrospective, focusing specifically on "new" RE resources built after RPS enactment and used to meet RPS compliance obligations in 2013—the most recent year for which the necessary data were available. In evaluating broader societal benefits and impacts, the study does not address either the direct costs of RPS procurement to load-serving entities, or the cost savings from reduced fuel, capital, and operations and maintenance (O&M) expenses associated with non-renewable generation. These were evaluated retrospectively in Heeter et al. (2014) and Barbose et al. (2015) and will be evaluated prospectively in future work.

The present study encompasses a subset of possible benefits and impacts from RPS programs, including possible environmental benefits associated with reductions in greenhouse gas (GHG) emissions, air pollution emissions, and water use. The study also evaluates the impacts of state RPS policies on jobs and economic development, wholesale electricity market prices, and natural gas prices. As explained further below, these latter three impacts do not necessarily represent societal benefits.

To evaluate these benefits and impacts, we rely on EPA's AVoided Emissions and geneRation Tool (AVERT) to estimate the fuel type and location of generation sources offset by new RE resources used to meet RPS compliance obligations in 2013. We then evaluate each of the benefit and impact categories identified above. For each benefit and impact category, we quantify the effects in physical units (e.g., tons of pollutants, gallons of water) and, where possible, in dollar-value terms as well, and estimate key sources of uncertainty. For each benefit and impact, we evaluate the aggregate effects of all state RPS programs, in combination, reporting results nationally and, where appropriate, by region and state; we do not analyze the effects of individual state RPS programs. Methodological details specific to each benefit and impact evaluation (and any important limitations therein) are presented in the corresponding section of the report.

This analysis represents the first detailed, national-level evaluation of the benefits and impacts from state RPS policies. However, we are not alone in addressing this topic. As already noted, many states have conducted their own state-level assessments of RPS outcomes, and the previous study in this report series (Heeter et al. 2014) highlighted the widely varying scopes and methods of those state-specific analyses, which complicates comparisons.[5] Chen et al. (2009), meanwhile, summarize state-level forecasts of RPS outcomes. In other cases, researchers have used statistical methods to try to distill the impacts of state RPS programs on 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). Still others have explored qualitatively or quantitatively a subset of the possible effects of

[5] The present study is specifically intended to build on these state-level assessments by applying a more consistent analytical framework. Note that, in addition to state-sponsored studies, a variety of more-academic studies have been conducted for specific states (e.g., for Michigan, see: Johnson and Novacheck 2015a,b; Novacheck and Johnson 2015)

RPS programs, sometimes coming to widely varying conclusions about the merits of these policies (Holt and Galligan 2013; Michaels 2008a; Michaels 2008b; UCS 2013).

Limitations and Caveats

Caveats and limitations associated with each benefit and impact assessment will be presented within the respective section of the report. In addition, a number of broader, cross-cutting considerations, limitations, and caveats deserve explicit note.

- **Applying Uniform Methods Nationally:** We estimate the potential benefits and impacts of state-level RPS standards in 2013 using common, standardized methods applied to all states collectively. With that in mind, individual states may have used or could use data and methods that provide a more-detailed picture of benefits that accrue to those specific states. For example, individual states may have better data on renewable sources used to meet RPS compliance obligations, more sophisticated tools to estimate which non-renewable plants are displaced, or locally vetted approaches to value benefits and impacts. Summaries of some of these state-level assessments are provided in Heeter et al. (2014).
- **Uncertainty in Benefits and Impacts Assessment:** A variety of uncertainties underlie our analysis. Where possible, we quantify the uncertainty in our results. In other cases, however, we qualify the study results and highlight areas of uncertainty not explicitly addressed in the analysis.
- **Distinguishing Potential Benefits from Impacts:** In presenting the approach and results of our analysis, we are careful to distinguish between potential societal *benefits* of RPS programs (GHG, air pollution, and water use reductions) and other *impacts* of those programs (gross jobs, wholesale electricity price reductions, 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—and the reported results represent the net effects. The impacts we evaluate are sometimes described as benefits—and indeed, may be benefits when viewed through the lens of an individual state or market participant. However, especially when viewed on a national or global scale, the impacts of RPS programs related to gross jobs and economic development and on wholesale electricity and natural gas prices are best considered resource *transfers*: benefiting some stakeholders at the expense of others. For these impact categories, we do not evaluate the *net* effects over the entire country or global economy and, as such, cannot assess whether or not these impacts reflect net costs or benefits. While such impacts might still be considered when judging the effects of state RPS programs, especially by state policymakers, it is important to acknowledge any offsetting effects involved on sectoral, regional, national, or even international scales.
- **Coverage of Benefit and Impact Categories:** Our analysis considers an important subset of—but not all—potential benefits and impacts from state RPS programs. For example, we do not assess the challenges of integrating renewable energy into bulk power and 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 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 noise, aesthetics, and others.
- **Considering Costs in the Equation:** Ultimately, a full understanding of their benefits, impacts, and costs is needed to comprehensively evaluate state RPS programs. The present analysis does not compare the benefits and impacts of RPS programs to their costs. As noted, previous research in this series (Heeter et al. 2014 and Barbose et al. 2015) summarized RPS compliance costs retrospectively, drawing partly from cost estimates developed by utilities and state regulatory agencies, and

highlighted the divergent methods used to assess RPS costs. Additional research is needed, and is planned within this research series, to evaluate RPS costs on a consistent basis across states and in a manner that can be more readily compared to benefits.

- **Evaluating Least-Cost Benefits and Impacts:** RPS programs are not the only, or necessarily the least-cost, way of achieving the benefits and impacts discussed in this paper. Rather, as widely recognized in economics literature, "internalizing externalities" is most efficiently achieved by directly pricing those externalities rather than through technology- or sector-specific policies. This is in part 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 2014a; 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 not be so great (Kalkuhl et al. 2012).
- **Estimating the Additionality of Benefits:** There are multiple drivers of RE additions, and our analysis does not seek to attribute the estimated benefits and impacts solely to RPS policies. Rather, our analysis evaluates the benefits and impacts of new RE used to meet RPS compliance obligations in 2013. Because of the leakage and spillover effects noted above, but 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 incremental benefits and impacts attributable *only* to state RPS programs.[6] 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). As two potentially offsetting considerations, however, RPS programs are likely supporting the continued operation of some pre-existing RE supply, which we do not consider in our analysis, nor do we consider any benefits or impacts associated with "surplus" RPS resources (i.e., new RE in operation in 2013 that was motivated by RPS requirements but, for one of several possible reasons, was not used for RPS compliance obligations in that year).[7]

Roadmap

The remainder of this paper is structured as follows. Section 2 describes the RPS policies and renewable resources included in our analysis; the approaches used for identifying the capacity, generation, and location of those resources; our approach for including those resources in AVERT; and the outputs of the AVERT analysis. Sections 3–8 then address each of the potential benefits and impacts in turn: GHG emissions, air pollution emissions, water use, jobs and economic development, wholesale electricity price suppression, and natural gas price suppression. In each of these sections, we introduce the benefit or impact category, describe our methods and their underlying uncertainties, and highlight key results. We conclude with a summary of our findings and their implications in Section 9.

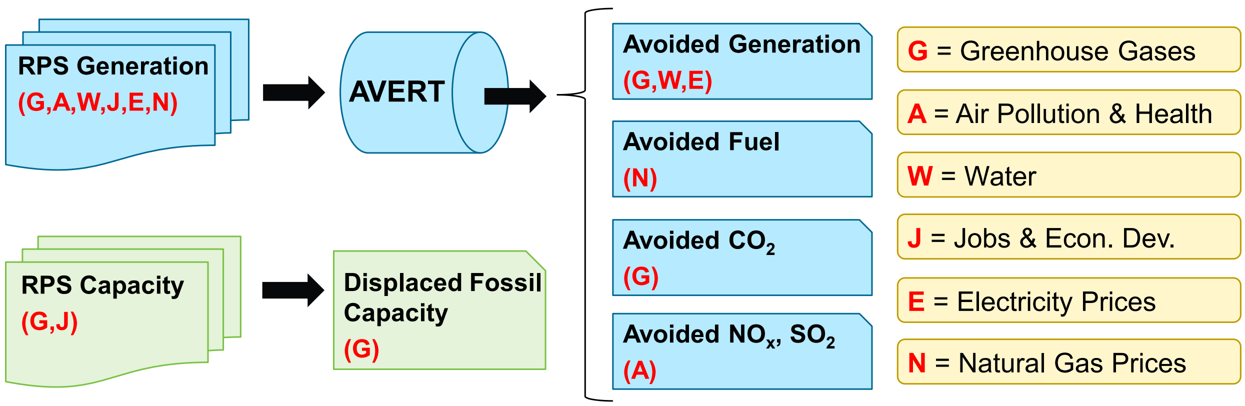
[6] For the same reason, estimates of RPS costs also may not be entirely attributable to RPS programs, specifically, as some portion of the renewable development used to serve RPS policies may have occurred in the absence of those policies.
[7] Surplus RPS resources might include, for example, long-term contracts that utilities sign for the purpose of meeting future RPS obligations or hedging against contract failures, as well as new RE resources outbid by other resources competing for RPS demand in markets dominated by short-term renewable energy certificate transactions.

2. Foundational Data and Analysis: RPS Resources and Displaced Fossil Generation

Compliance with RPS obligations in 2013 was achieved with 98 TWh of new renewable electricity generation, representing 2.4% of total U.S. electricity generation in that year and resulting in a 3.6% reduction in total fossil fuel generation. Over the two-year period from 2013 through 2014, an average of almost 5,600 MW of new renewable capacity per year was built to service RPS requirements. These effects drive the benefits and impacts analyses described in later sections of this paper.

Overview

The RPS benefits and impacts estimated in this study require a common basis of information about renewable resources used for RPS compliance in 2013 and about the associated displacement of fossil-fuel generation, capacity, fuel use, and emissions (see Figure 2.1). We compile data on renewable resources used to meet 2013 RPS compliance obligations, drawing from state and utility RPS compliance filings and other relevant sources. Those data are used directly within each of the individual benefit and impact analyses. Those data also compose the key inputs for modeling with AVERT to estimate displaced generation, fuel, and emissions (CO_2, NO_x, SO_2) from other (primarily fossil-fueled) power plants. Separately, data on RPS-related RE capacity additions are compiled and used directly within the analyses of GHG benefits and gross jobs impacts, and also used to estimate displaced fossil generation capacity. The remainder of this section describes each of these data elements and analytical steps in further detail.



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

Figure 2.1. Foundational data and analysis to support RPS benefits and impacts estimates

Renewable Generation Used for RPS Compliance

Compliance with RPS obligations is typically demonstrated through the use of renewable energy certificates (RECs), which represent the renewable attribute associated with electricity generated from renewable resources. Some state RPS programs allow RECs to be transacted separately ("unbundled") from the underlying electricity commodity, while others require RECs to remain bundled with the associated electricity. Regardless of how RECs are procured, LSEs generally demonstrate compliance by documenting that they have retired the requisite number of RECs to meet RPS compliance obligations in a given year. That documentation provides a record of exactly which resources were used for RPS compliance.

For the AVERT modeling and the individual benefit and impact analyses within the present study, we specify the quantity and attributes of RPS generation based on the specific set of RECs retired for each state's 2013 RPS compliance obligations.[8] We employ several key accounting conventions throughout these analyses, which collectively tend to constrain the estimated benefits and impacts (in part by limiting the scope of our analysis to those RE projects most likely to have been at least partially motivated by state RPS policies):

- **New RE Only**: For each state RPS, we count only those RECs associated with RE facilities constructed after the date of RPS enactment[9]
- **Exclude Excess RPS Procurement**: LSEs in some states have over-complied with RPS obligations; however, we count only those RECs required to meet each LSE's minimum RPS compliance obligations in 2013.[10]
- **Exclude Non-RE Resources Used for RPS Compliance:** Some states allow resources other than renewable electricity—such as energy efficiency or natural gas-fired combined heat and power—to count toward RPS compliance; however, we exclude those resources from our analysis.
- **Exclude Hawaii:** The AVERT model only covers the continental United States, thus Hawaii's RPS is excluded from our analysis.

To assemble these data, we rely principally on annual RPS compliance filings issued by individual LSEs in states with regulated utilities, or by state public utility commissions in restructured states with competitive retail markets.[11] We supplement those sources with data from regional or state REC tracking systems, which provide additional, important details about RPS-eligible facilities for each state.

The various benefit and impact analyses require that we segment REC retirement data for each state according to the state in which the plant is located (which may differ from where the associated RECs are retired), the plant vintage, and its fuel type. We use the following fuel type classifications across all states: wind, utility-scale photovoltaics (PV), rooftop PV, concentrating solar power (CSP), landfill gas (LFG), biomass, geothermal, and hydroelectric. We also segment the REC data according to whether the associated electricity is delivered into the same region in which the REC is retired. Specifically, AVERT simulates fossil fuel[12] displacements in each of the ten regions shown in Figure 2.2, based on renewable electricity delivered or consumed within the region. Where unbundled RECs were used for RPS compliance, we segment the REC retirement data according to the AVERT region into which the associated electricity was delivered, building on the approach used by AWEA (2014) to estimate the air quality benefits of wind energy. In making these determinations about physical delivery, we rely on each

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[8] Depending on the state, some portion of RECs retired for 2013 RPS compliance obligations may have been generated in prior years and banked for later use. Similarly, some portion of RECs physically generated in 2013 was banked for use in later years. For the purpose of estimating RPS benefits and impacts in the year 2013, we ignore distinctions related to REC vintage, and simply treat all RECs retired in 2013 as though they were generated in the same year.

[9] In some states, pre-existing resources are ineligible for RPS compliance or are relegated to a secondary tier, while other states may allow certain pre-existing resources to qualify for RPS compliance. Only in the latter case was any judgement required in order to exclude RECs from pre-existing resources. To the extent that RPS policies support the continued operation of existing facilities, limiting the analysis to new facilities will tend to understate the possible benefits of RPS policies.

[10] This convention is most significant for Texas and Iowa, which have substantially exceeded their RPS requirements. LSEs in a number of other states have also procured more RECs than strictly required for RPS compliance, in some cases banking excess RECs for compliance in future years.

[11] Specifically, we relied on annual RPS compliance filings issued by all or most obligated LSEs in Arizona, California, Colorado, Kansas, Michigan, Missouri, Montana, Nevada, New Mexico, Oregon, and Washington. For the following states, we instead relied primarily on annual summary compliance reports issued by the state public utility commission or other agency: Connecticut, Maine, Massachusetts, Minnesota, New Hampshire, New York, Rhode Island, Texas, and Wisconsin. Finally, REC retirements were derived entirely from REC tracking system data for LSEs in Delaware, Illinois, Maryland, New Jersey, North Carolina, Ohio, Pennsylvania, and Washington, D.C.

[12] AVERT includes a small number of non-fossil generators, and the emissions displaced from these facilities are included in the totals reported for fossil generation.

state's geographic eligibility and deliverability rules.[13] Importantly, the data sources for many states and regions did not provide exactly the information needed to segment REC retirements in the various ways described above; thus, additional state- or regionally specific intermediate steps and assumptions are often required.[14]

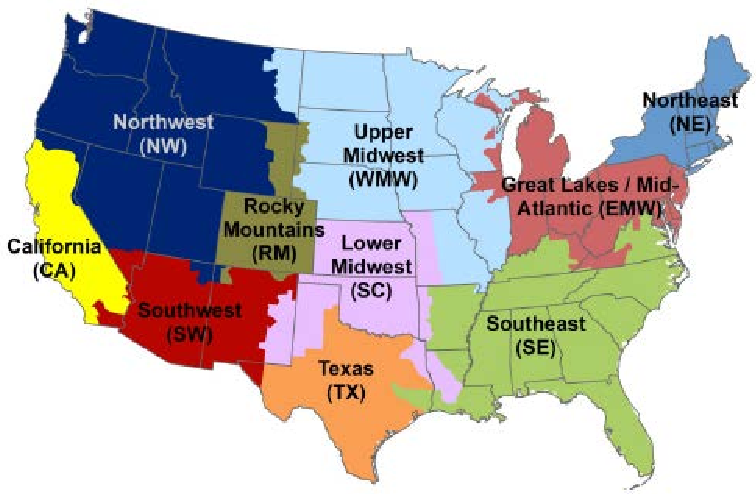


Figure 2.2. AVERT regions

(Source: EPA 2014)

Based on the data sources and process described above, 98 TWh of new renewable electricity was generated to serve RPS compliance obligations in 2013. This equates to roughly 2.4% of total U.S. electricity generation and 39% of total U.S. non-hydroelectric renewable electricity generation in that year.[15] Figure 2.3 shows where these RPS resources are located and their relative contribution to each state's total electric generation supply. The percentages shown partly reflect the relative stringency of each state's target, but are also impacted by the extent to which RPS states rely on new, in-state

[13] Although RPS compliance in restructured states is typically achieved through the purchase and retirement of unbundled RECs, eligibility rules in those states typically require that the associated electricity is either generated in or delivered to the regional power market, which coincides with the respective AVERT region. Thus, in the vast majority of cases in which unbundled RECs are used for RPS compliance, we assume that the associated electricity is delivered to the corresponding AVERT region. The most significant exception in terms of absolute MWh is California, where roughly 34% of 2013 REC retirements from new renewables were sourced through "firmed and shaped" products, mostly from the Pacific Northwest; we assume that those contracts result in no incremental electricity delivered into California, and thus that the physical delivery of electricity from those facilities remains within their region of origin. The other significant case in which unbundled RECs are used for RPS compliance without physical delivery of electricity into the region is North Carolina, where we estimate that roughly 55% of REC retirements from new renewables are associated with unbundled RECs procured from wind facilities in Texas.

[14] For the Great Lakes/Mid-Atlantic (EMW) region, public reports available through PJM's GATS-EIS provide data on REC retirements by state and fuel type, but no information about the vintage or location of the underlying resources. To segment those REC retirements by vintage and state-of-origin, we allocated REC retirements for each state RPS across the set of eligible facilities. A similar approach was also used to segment REC retirements for North Carolina's RPS by vintage and state-of-origin. For most states in the WMW region, no information was readily available about the fuel mix of RECs retired in 2013; thus, total REC retirements for each state were simply allocated across eligible plants, based on the state(s) for which each facility is eligible, as identified in M-RETS public reports. For other regions, RPS compliance reports directly provided most of the necessary information, though limited assumptions or extrapolations were still often required, for example, where compliance data were unavailable for small LSEs.

[15] Total non-hydroelectric renewable generation in the United States equaled 254 TWh in 2013 (EIA 2015a), including both the 98 TWh of new renewable electricity generation applied towards RPS compliance obligations as well as roughly 50 TWh of pre-existing renewables also used to meet RPS requirements. Thus, RPS programs collectively represented 58% of total U.S. non-hydroelectric renewable generation. Of the 106 TWh of renewable generation not used to meet RPS compliance obligations, roughly 60 TWh was sold into voluntary green power markets (Heeter et al. 2014).

resources—as opposed to existing and/or out-of-state resources. Accordingly, the figure also illustrates the role of cross-state trade in meeting RPS compliance obligations; for example, many states without RPS policies (GA, ID, IN, KY, ND, OK, SD, UT, VA, WV, and WY) produced renewable electricity used to serve RPS compliance obligations in other states in 2013.

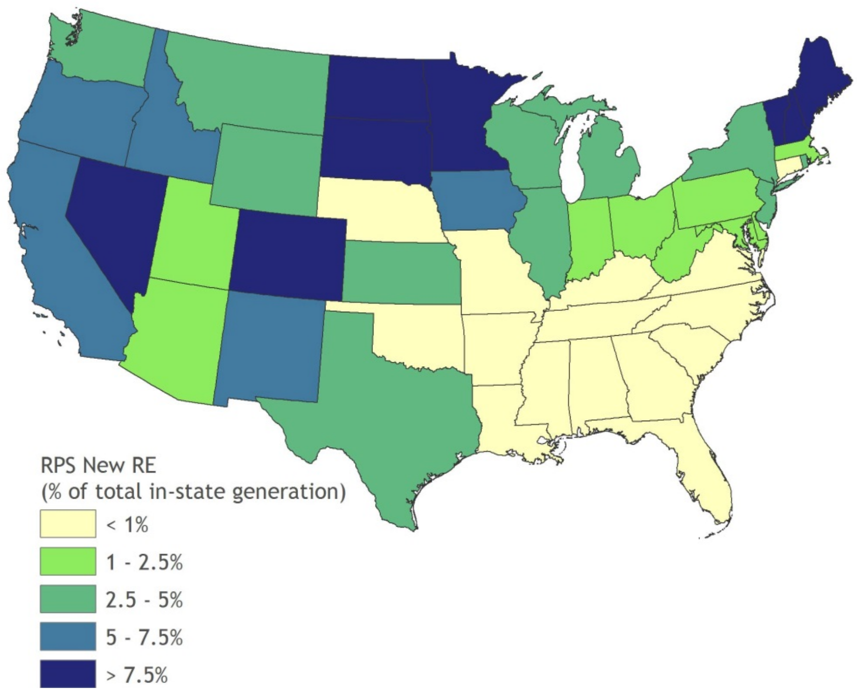
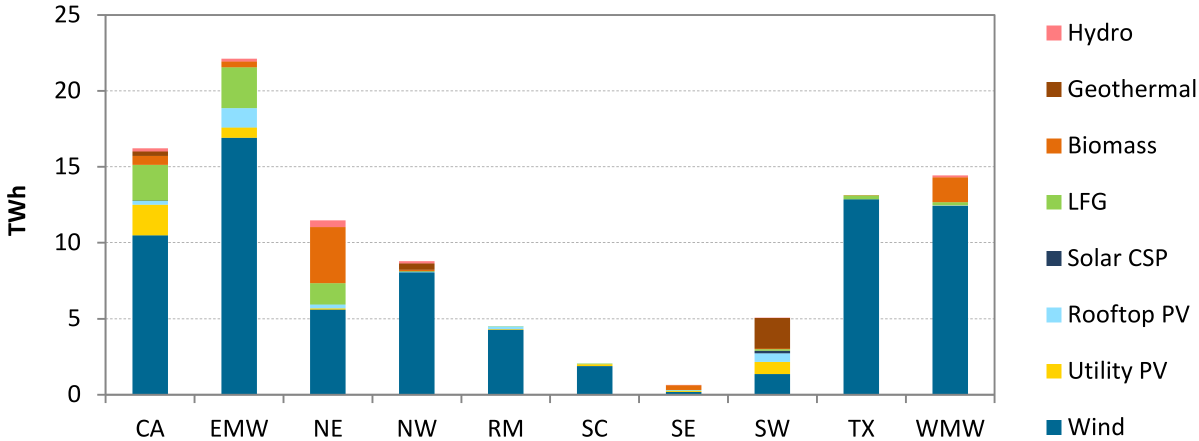


Figure 2.3. New RE for RPS compliance based on plant location

Figure 2.4 shows the distribution of new renewable electricity used for 2013 RPS compliance, based instead on the AVERT region into which the electricity was physically delivered and the composition of those resources. These data compose the primary inputs for the AVERT modeling. The regional distribution reflects both the volume of retail sales in each region, as well as the relative stringency of RPS targets. Thus, for example, RPS deliveries to the Great Lakes/Mid-Atlantic (EMW) region were large as a result of the sizable amount of retail load subject to RPS requirements, while RPS deliveries to the SE region were quite small as a result of the absence of RPS policies throughout much of that region. As also shown, wind power was the largest renewable fuel type used in each region, composing 75% of total RPS generation nationally, though clearly some regions have a more diverse mix, reflecting greater availability of particular resource types and/or resource-specific carve-outs.



CA=California, **EMW**=Great Lakes/Mid-Atlantic, **NE**=Northeast, **NW**=Northwest, **RM**=Rocky Mountains, **SC**=Lower Midwest, **SE**=Southeast, **SW**=Southwest, **TX**=Texas, **WMW**=Upper Midwest

Figure 2.4. New RE delivered to each AVERT region for 2013 RPS compliance

Displaced Fossil Generation

We rely on EPA's AVERT model to estimate the type and location of fossil generation sources offset by new renewable sources meeting RPS compliance obligations in 2013, along with the associated reduction in fuel consumption and emissions (CO_2, NO_x, SO_2). As described in EPA (2014a), this model uses historical data to estimate changes in generation and emissions within each AVERT region resulting from an increase in renewable electricity (or energy efficiency). In particular, these impacts are estimated on an hourly basis for individual electric generating units, based on statistical relationships derived from historical data reported through the EPA's Acid Rain Program.[16] Many alternative methods exist to estimate displacement effects (Synapse 2015). As described in EPA (2014a) and Synapse (2015), AVERT represents an intermediate approach among the available options: it is more complex than using a simple regional marginal displacement (or emission) rate, but less complex than a full production cost model or a highly region-specific and detailed statistical analysis.

AVERT has the benefit of providing a consistent approach to estimating historical displacement on a national basis and in every region of the contiguous United States. As with any model, however, AVERT has its limitations, as described in the user guide (EPA 2014a). For example, the model is insensitive to the location of renewable generation within a given region and therefore may not accurately model the impacts of highly localized RE policies (as is the case in the SE region, where only one state has RPS requirements). Given its calibration to historical data, AVERT also has limited ability to accurately model the impacts of very large RE programs. As a rule of thumb, the user guide recommends limiting RE additions to 15% of the fossil generation load in any hour; this limit was exceeded for a number of regions with relatively aggressive RPS targets (although in no case in our analysis did RE generation exceed 15% of fossil generation on an annual basis). The model also does not capture interactions across regions, which is potentially significant, particularly as balancing authorities seek greater levels of

[16] In our analysis, we used AVERT regional data files for the year 2013. Because the statistical relationships in those files already reflect the effects of RPS resources operating in 2013, we modeled the impact of those resources by "removing" them (i.e., treating them as negative generation sources) rather than by adding them in as additional renewable resources, beyond what was already in operation in 2013. Furthermore, renewable generation quantities were input into AVERT as hourly profiles. This required translating the annual generation quantities shown in Figure 2.4 into aggregate hourly generation profiles for each region, using wind and solar PV profiles built into AVERT and profiles from Brinkman et al. (forthcoming) for other renewable fuel types.

coordination for renewables integration. These and other model limitations are discussed more fully in EPA (2014a).

Based on the renewable generation delivered to each region, the displaced generation resources estimated with AVERT are shown in Figure 2.5 (by state) and Figure 2.6 (by AVERT region). In aggregate, new renewable resources used to serve RPS compliance obligations in 2013 reduced total U.S. fossil generation by roughly 3.6% in that year, though the percentage of fossil generation displaced varies widely across regions, from just 0.1% of 2013 fossil generation in the Southeast (SE) region to 13.9% in California, reflecting the varying stringency and prevalence of RPS policies. Most of the displaced fossil generation is estimated by AVERT to have been gas-fired (55% of the total), though substantial amounts of coal-fired generation were also found to be displaced, especially in regions with a coal-heavy fossil generation mix, in part reflecting significant levels of wind generation during off-peak hours when coal is on the margin. Other AVERT outputs are summarized in Section 3 (reduced CO_2 emissions), Section 4 (reduced SO_2 and NO_x emissions), and Section 8 (reduced natural gas consumption).

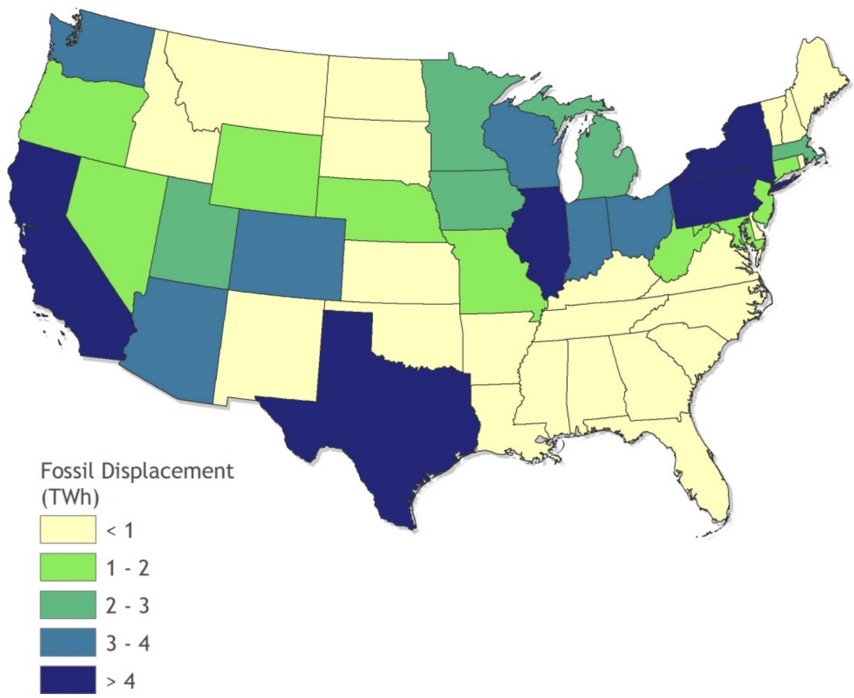
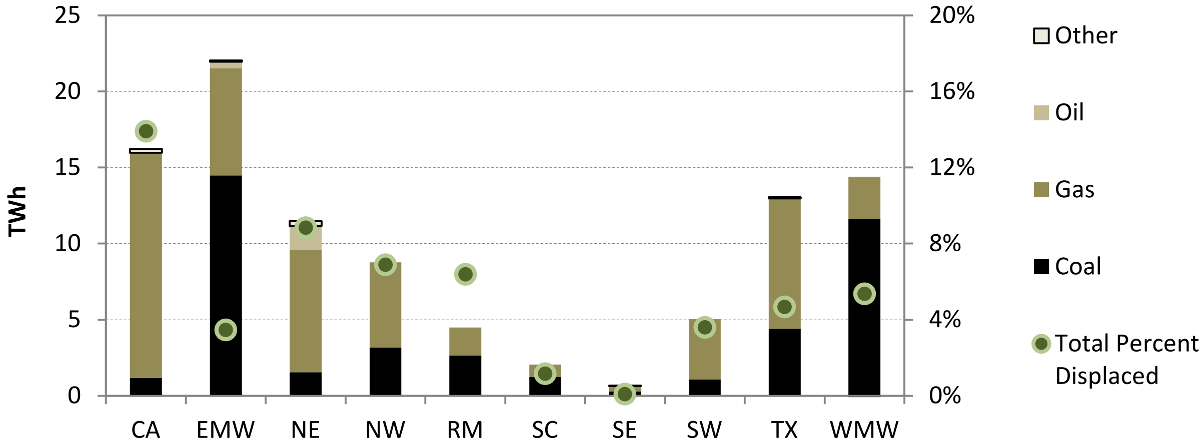


Figure 2.5. Displaced fossil generation by state



CA=California, **EMW**=Great Lakes/Mid-Atlantic, **NE**=Northeast, **NW**=Northwest, **RM**=Rocky Mountains, **SC**=Lower Midwest, **SE**=Southeast, **SW**=Southwest, **TX**=Texas, **WMW**=Upper Midwest

Figure 2.6. Displaced fossil generation by AVERT region

RPS Capacity Additions and Displaced Fossil Generation Capacity

Estimates of the life cycle GHG benefits and gross jobs impacts of state RPS policies require information about the amount and type of RE capacity additions associated with these policies, and in the case of the GHG benefits, about the corresponding amount and type of displaced fossil capacity additions. For these capacity-driven benefits and impacts, the relevant set of RPS capacity additions are those that yielded "RPS-driven" benefits and impacts occurring in the year 2013, regardless of whether the renewable capacity was used to meet compliance obligations in 2013. Specifically, we focus on RPS-related capacity additions completed from 2013 through 2014, and estimate the benefits and impacts based on the average annual capacity additions over that two-year period. We focus on that particular time period because some portion of capacity additions completed in 2014 were under construction during 2013, and therefore yielded benefits and impacts in that year. Moreover, averaging capacity additions over a multi-year period smooths out some of the volatility in annual renewable capacity build rates.

Data on renewable generation capacity additions are derived from multiple sources, including Ventyx (2015), AWEA (2015), GTM Research and SEIA (2015), EPA (2015c), Wiser and Bolinger (2015), and Bolinger and Seel (2015). Not all renewable capacity additions are associated with state RPS programs; in general, we consider projects to be "RPS-related" under either of the following conditions: (a) the off-taker of power and RECs is subject to state RPS compliance obligations, or (b) the facility sells its power on a merchant basis into regional energy markets administered by a regional transmission organization (RTO). The one exception to that decision rule occurs if the individual off-taker (or the RTO market as a whole) has already fully met its final-year RPS targets, in which case the renewable capacity addition is not counted as RPS-related. This exception is triggered principally for LSEs in Texas and Iowa, which had already achieved their respective final-year RPS targets.

Given the above set of data sources and decision rules, we estimate that RPS-related renewable capacity additions over the 2013–2014 period averaged almost 5,600 megawatts (MW) per year. As shown in the pie chart inset into Figure 2.7, the largest portion of these capacity additions is utility-scale PV (48%), followed by wind (19%), rooftop PV (17%), CSP (11%), and much smaller contributions from biomass, LFG, and geothermal.[17] These capacity additions are distributed across 33 states, though almost half are located in California, reflecting the rapid and recent build-out of renewable capacity to meet 2020 RPS targets, including the completion of a number of large utility-scale PV projects.

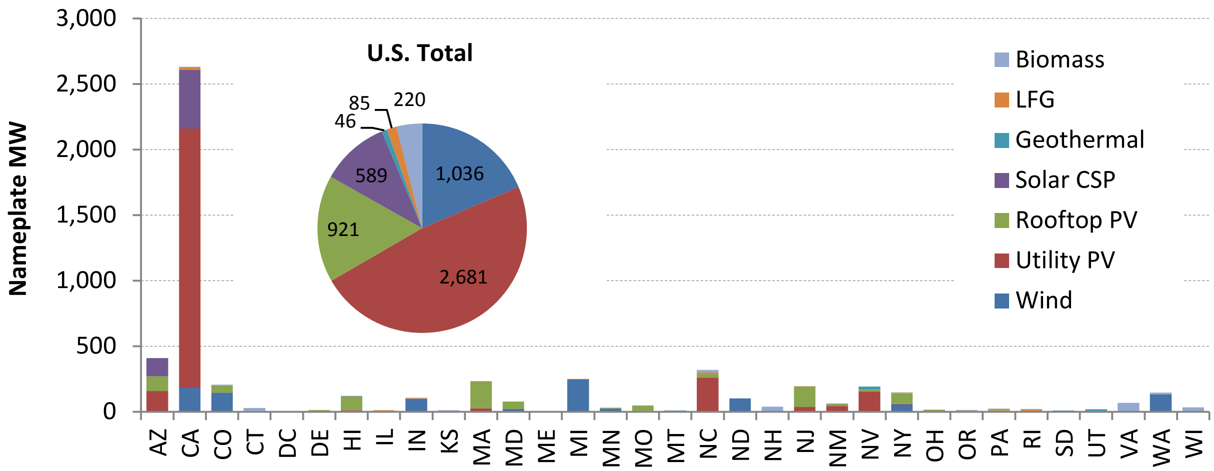


Figure 2.7. RPS capacity additions by state

(annual average during 2013–2014)

Based on the RPS-related capacity completed during the 2013–2014 period, we estimate the corresponding amount and type of displaced fossil generation capacity. This information is used only for the purpose of estimating avoided GHG emissions associated with the construction phase of new fossil generation facilities, which is ultimately a minute component of the overall GHG emission benefits. As such, we employ a simplified approach to estimate avoided fossil capacity additions. For each type of renewable capacity, we stipulate its capacity credit (95% for geothermal, biomass, and LFG; 75% for CSP; 45% for PV; and 15% for wind), drawing from the relevant literature (Sims et al. 2011).[18] We further assume that, for all non-solar renewable capacity additions, 70% of displaced fossil capacity consists of combined cycle gas turbines (CCGTs), and 30% consists of gas-fired combustion turbines (CTs). For solar capacity additions, whose profiles more closely coincide with peak demand, we assume the inverse: 70% CTs and 30% CCGTs. Based on this simple methodology, we estimate that renewable capacity additions over the 2013-2014 period displaced, on average, more than 2,500 MW of fossil capacity per year, consisting of 1,600 MW of CCGTs and 960 MW of CTs.[19] .

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[17] In contrast, the distribution in cumulative RPS capacity additions is more heavily weighted towards wind power, representing 70% of all RPS-related RE capacity additions through 2014, compared to 24% solar, 5% biomass, and 1% geothermal (Barbose 2015).

[18] The capacity credit measures the percent of a renewable power plant's nameplate capacity that can be counted on to meet a system's planning reserve or resource adequacy requirements. In this context, it measures the amount of new fossil or other capacity that would not be needed as a direct result of adding the renewable plant. Capacity credit differs from capacity factor, which is a fraction that reflects the amount of electricity generated by a plant over a certain period of time (typically a year) divided by the electricity that could have been produced by that plant if it were to operate at its full nameplate rating over the full duration of that period.

[19] To be sure, this estimate is highly approximate and does not account for various real-world complexities, such as the fact that avoided fossil capacity additions might not occur until some future point in time, in cases where a region had surplus generation capacity in 2013 and 2014. That said, these uncertainties and approximations are ultimately insignificant within the context of our analysis, as the GHG emission reductions associated with avoided fossil generation capacity are shown in the next section to constitute less than 1% of the total avoided GHG emissions.

3. Greenhouse Gas Emissions and Climate Change Damage Reduction Benefits

Renewable generation used to meet 2013 RPS compliance obligations reduced national life cycle GHG emissions by an estimated 59 million metric tons of carbon dioxide-equivalent (CO_2e). These emission reductions in 2013 produced an estimated $2.2 billion of global benefits in the form of lower future climate change damages when applying a "central value" for the social cost of carbon (SCC). Benefits estimates span $0.7 billion to $6.3 billion across the full range of SCC estimates considered here. These global benefits of new renewable energy meeting RPS policies are equivalent to 2.2¢/kWh-RE in the central value case, and 0.7 to 6.4¢/kWh-RE across the full range.

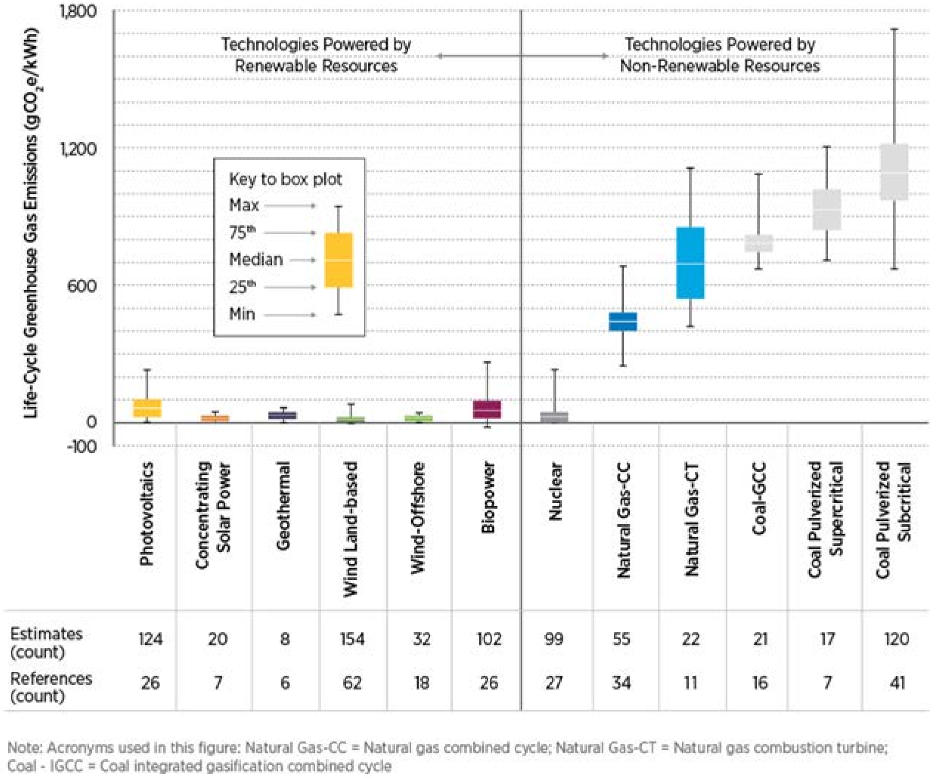
Introduction

Scientists predict significant changes to the Earth's climate owing to both past and future GHG emissions. Changes include higher average temperatures, increased frequency and intensity of some types of extreme weather, rising sea levels, and ocean acidification (IPCC 2013; IPCC 2014b). As highlighted in Melillo et al. (2014), these changes are expected to impose a wide range of damages in the United States: threatening human health and well-being through more extreme weather events, wildfire, and decreased air quality; putting infrastructure at risk; jeopardizing water quality and supply; disrupting agricultural production; and negatively affecting ecosystems and biodiversity.

EPA (2015d) finds that efforts to limit climate change damages through reductions in GHGs can offer many benefits to the United States, and there is growing recognition of the desirability of near-term actions to limit emissions (IPCC 2014a; Luderer et al. 2013; Nordhaus 2013). Responding to this challenge, EPA has established GHG emission limits for—among other things—existing and new power plants (EPA 2015a; EPA 2015b).

RE technologies generally have low GHG emissions in comparison to fossil energy sources. Most RE sources have no direction emissions and, even when considering all life cycle stages from upstream materials requirements to operations and decommissioning, RE technologies typically have very low GHG emissions. Figure 3.1 summarizes an NREL systematic review of the available life-cycle literature; see also www.nrel.gov/harmonization. State-level RPS programs are therefore among the many types of policies that have been or that might be used to reduce GHG emissions. Previous research has found a statistical link between RPS programs and carbon emission reductions (Eastin 2014; Yi 2015). In this section, we estimate the potential life cycle GHG benefits of new RE used for RPS compliance, quantifying the value of those GHG reductions in mitigating the severity of climate-related damages.[20]

[20] Current actions to limit GHGs can also be considered as one method of reducing the longer-term cost of future policies to reduce GHGs. Some U.S. states and regions have already enacted carbon-reduction policies; the U.S. Congress has considered such policies in the past; and the EPA has proposed emission limits for power plants (Luckow et al. 2015). As a result, many utilities already regularly consider the possibility of future policies to reduce GHGs in resource planning, and thereby treat RE sources as options for reducing the possible future costs of climate mitigation (Barbose et al. 2008; Bokenkamp et al. 2005; Luckow et al. 2015).



Note: "References" refers to the number of literature citations that underlie each "box and whisker"; "estimates" exceed "references" because many literature citations include multiple, independent estimates.

Figure 3.1. Summary of life cycle GHG emissions from electricity generation technologies

(Source: DOE 2015)

Methods

Our methods to value the potential GHG benefits from state RPS programs involve first estimating the life cycle GHG reductions from new RE serving RPS compliance in 2013, and then quantifying the economic value of those reductions based on a range of social cost of carbon (SCC) estimates (see Figure 3.2). These methods are similar to those used in DOE's recent *Wind Vision Report* (DOE 2015), and are broadly consistent with methods used by U.S. regulatory agencies (GAO 2014) and academic researchers (Buonocore et al. 2015; Callaway et al. 2015; Cullen 2013; Graff Zivin et al. 2014; Johnson et al. 2013; Kaffine et al. 2013; McCubbin and Sovacool 2013; Novan 2014; Siler-Evans et al. 2013; Shindell 2015).

We start with AVERT-estimated power sector CO_2 emissions reductions from new RE used to meet RPS compliance obligations in 2013. Those estimates, however, only consider combustion-related emissions.[21] We adjust these figures to account for life cycle impacts by combining AVERT combustion-related

[21] Combustion-related emissions estimates consider CO_2 emissions from combustion of fuels during the operation of power plants. They do not consider two other important sets of emissions attributable to electricity generation: GHG emissions from other life cycle stages and GHG emissions from non-CO_2 gases. Life cycle assessment procedures are needed to estimate GHG emissions from upstream materials supply, equipment manufacturing and construction, operations and maintenance, and plant decommissioning. In addition, consideration of other potent GHGs beyond CO_2 may be particularly important for methane released in coal mining, oil production, and natural gas production and transport.

emissions with life cycle, non-combustion emission values for each generation technology, based on results developed in NREL's LCA Harmonization study (www.nrel.gov/harmonization). The additional life cycle stages that we consider include: (1) ongoing, non-combustion-related emissions during the fuel cycle, such as those that occur during the production and transport of fuels and through other operational activities (e.g., operation of maintenance vehicles, auxiliary heating, etc.); and (2) construction-related emissions (i.e., emissions from materials, equipment, and construction).[22,23] By applying these life cycle adjustments, we capture avoided fuel cycle and construction emissions from displaced fossil generation and capacity while also accounting for increased fuel cycle and construction emissions from RE generation and capacity used to meet RPS standards in 2013.

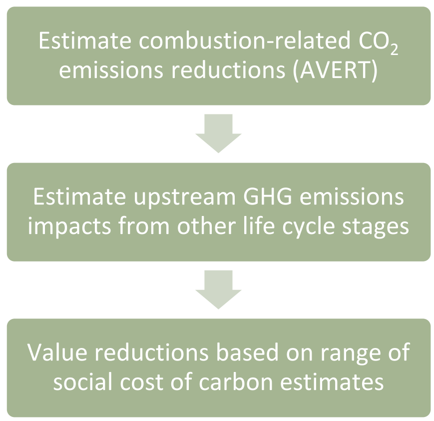


Figure 3.2. GHG benefits methods overview

We then estimate the economic benefits of RPS compliance in the form of reduced climate change damages using SCC estimates.[24] The SCC reflects, among other elements, monetary damages from the impacts of climate change on agricultural productivity, human health, property damages, and ecosystem services (IWG 2010; IWG 2015). U.S. government regulatory bodies regularly use the SCC when formulating policy (GAO 2014; Kopp and Mignone 2012), supported by estimates provided by the U.S. Interagency Working Group (IWG) on the Social Cost of Carbon (IWG 2010; IWG 2015). The IWG SCC

[22] The decommissioning stage is not included in the analysis, because we are evaluating emissions reductions in 2013, and do not presume that state RPS programs impacted plant decommissioning decisions in that year. Furthermore, decommissioning-related GHG emissions are typically very small compared to the other life-cycle stages (<1%) (see studies linked at www.nrel.gov/harmonization), and thus any bias introduced by not considering decommissioning will be small.

[23] An extensive review and analysis of previously published life-cycle assessments (LCAs) on electricity generation technologies was conducted through NREL's LCA Harmonization project (see http://www.nrel.gov/harmonization). Based on that literature, we developed median life-cycle, non-combustion GHG emission values for each generation technology, and for both the fuel cycle and construction phases. To estimate non-combustion GHG emissions from the fuel cycle, we use the electricity production estimates (in MWh) provided earlier in Section 2 for both renewable energy (increased under RPS) and fossil energy (displaced by RPS) technologies and apply the median, literature-derived estimates of technology-specific, non-combustion fuel-cycle GHG emissions. To estimate GHG emissions from construction, we use the capacity estimates (MW) provided earlier for both the average renewable energy capacity additions over the 2013 to 2014 timeframe to serve RPS programs and the related displaced fossil-fuel capacity, and we then apply the median, literature-derived estimates of technology-specific, construction-related GHG emissions. This approach was used in DOE (2015), where the methods are described in greater detail.

[24] Research has sought to estimate the magnitude and timing of climate-change impacts, damages, and associated costs (IPCC 2014a; IPCC 2014b; IWG 2010; IWG 2015; Melillo et al. 2014; Weitzman 2012). Because of the uncertainties involved, estimates of the SCC span a wide range (IPCC 2014b; Tol 2011; Weyant 2014), leading some to suggest possible improvements to SCC estimates and procedures (Ackerman and Stanton 2012; Arrow et al. 2013; Johnson and Hope 2012; Kopp et al. 2012; Pizer et al. 2014; Weyant 2014) or even to question the use of these estimates (Pindyck 2013).

estimates represent global future damages from GHGs emitted in a particular year. Reflecting the uncertainties involved, the IWG (2015) provides four SCC estimates: a "low" case, a "central value" case, a "high" case, and a "higher-than-expected" case intended to account for a much less likely outcome with a more extreme impact. For our purpose, the monetary value of RPS compliance is estimated based on all four IWG estimates, for 2013. The central value SCC for 2013 is $37 metric ton (MT) of CO_2 (in 2013$).[25] The low case is $12/MT, the high case is $59/MT, and the higher-than-expected case is $106/MT.

Several issues related to the methodology and associated limitations, some discussed earlier, deserve note:

- We do not fully consider the possible erosion of GHG benefits due to increased cycling, ramping, and part loading required of fossil generators in electric systems with higher penetrations of variable renewable generation. This omission, however, will not meaningfully bias our results, as the available literature clearly demonstrates that this impact is quite small, even at much higher levels of renewable energy supply than evaluated here.[26]
- Our assessment of construction-related life cycle emissions is based on average renewable capacity additions over the 2013 through 2014 time frame (nearly 5,600 MW in total) and—relying on capacity credit assumptions—avoided fossil capacity (more than 2,500 MW in total). The application of these emissions to 2013 is somewhat speculative, especially because avoided fossil capacity additions might not be expected to occur until several years after the RE capacity is built. Nevertheless, despite potentially being realized in later years, these benefits are arguably attributable to the additional RE supported by the RPS policies.
- We assume that biomass combustion emissions (other than landfill gas) are entirely offset by carbon absorption to produce the biomass feedstocks, and we do not seek to estimate land-use related emissions. Specifically, we do not consider the indirect effects of the provision of biomass to the power plant and whether that provision could have induced a change in land use (whether domestically or internationally) with an associated GHG emissions impact. This topic lacks a clear consensus by which to quantify GHG emissions for the purpose of this paper, especially given the wide range in estimates of land-use-related biomass emissions (IPCC 2011, Warner et al. 2013). For landfill gas, in contrast, we take a conservative approach and assume that landfill gas used for electricity production would otherwise have been flared (with no net change in GHG emissions at the plant), rather than vented (which would avoid more-potent methane GHG emissions).
- Though IWG SCC estimates span a large range, an even wider range exists in the literature. Also, as recommended by the IWG and others (IWG 2015; Pizer et al. 2014), we rely upon global SCC estimates: this means that the results are reflective of future global benefits (discounted to the present), only a portion of which would directly accrue to the United States and the vast majority of which would occur in future years. We apply the IWG SCC estimates to the estimated life cycle GHG emissions savings (in CO_2e).[27]

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[25] We present all IWG SCC estimates in 2013$.

[26] Studies have found that the GHG benefits of variable renewables are diminished by, at most, less than 10% (Göransson and Johnsson 2009; Gross et al. 2006; Pehnt et al. 2008; Perez-Arriaga and Batlle 2012), with far lower levels anticipated at smaller penetrations of RE in large electric systems (Fripp 2011; Valentino et al. 2012). In the most sophisticated of the studies, Lew et al. (2013) find the impact to be negligible (less than 1%).

[27] The application of IWG's SCC estimates to life cycle CO_2e creates some inaccuracy, as the IWG is clear that its values may not be appropriate for GHGs other than CO_2, even when translated into CO_2e based on global warming potential (IWG 2010). The level of inaccuracy is unclear, but given the scale of non-CO_2 gases in total life cycle emissions, this inaccuracy is likely considerably smaller than the range in SCC estimates applied in the present analysis. IWG intends, in the future, to develop methods to value non-CO_2 GHGs.

- Finally, our methodology presumes that carbon cap-and-trade programs were effectively non-binding in 2013; otherwise, the benefits of RPS compliance should arguably be valued at carbon allowance prices to reflect savings in the cost of complying with the cap, not at the estimated cost of climate damages (Cullen 2013; Siler-Evans et al. 2013).[28]

RESULTS

New RE used to meet RPS obligations in 2013 reduced life cycle GHG emissions by an estimated 59 million MT of CO_2e (see Figure 3.4). These emission reductions are driven almost entirely by direct combustion-related GHG emissions reductions from avoided fossil fuel generation, equal to 61 million MT of CO_2 (3% of 2013 power sector emissions). As shown in Figure 3.3, combustion-related emissions reductions are concentrated in the Great Lakes and Mid-Atlantic regions, Texas, California, Colorado, and Washington, reflecting both the locations with the most-aggressive RPS standards and the regions in which high carbon-emitting coal plants are more likely to be displaced. Because fossil plant displacement occurs not only within RPS states but also outside of those states, GHG emissions reductions extend beyond the 29 states and Washington, D.C. with RPS compliance obligations in 2013.

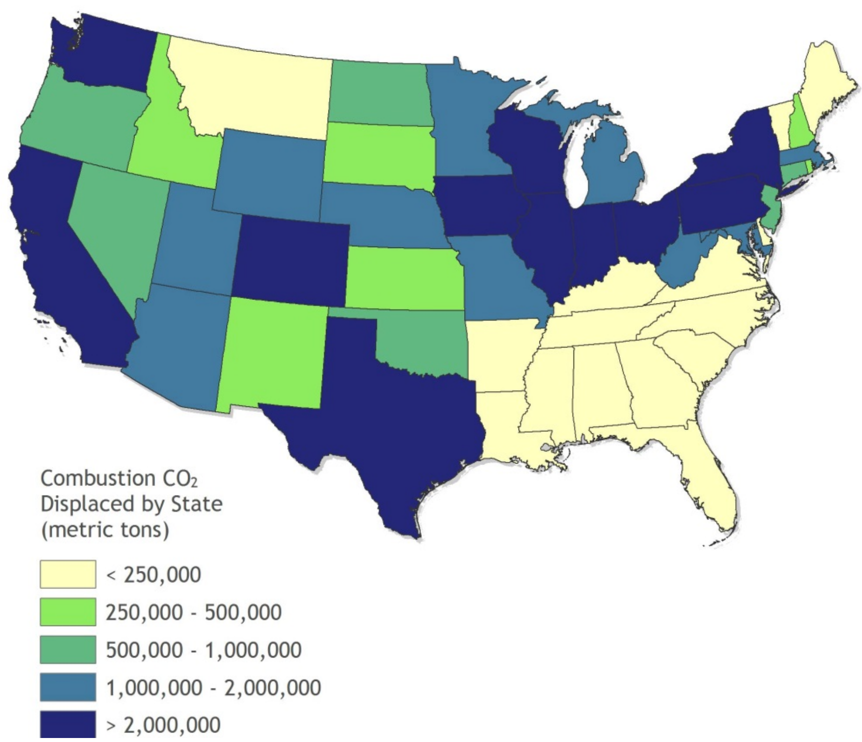

Figure 3.3. Combustion-related CO_2 emissions displaced by state from RPS compliance

In addition to direct combustion-related GHG emissions reductions from avoided fossil fuel generation, RPS programs also displace non-combustion fuel-cycle emissions from fossil energy supply and, to a

[28] This is because, under strictly binding caps, RE does not reduce emissions per se, but instead alleviates the need to reduce emissions elsewhere in order to achieve the cap. In 2013, GHG cap-and-trade programs existed in the Northeastern United States (via the Regional Greenhouse Gas Initiative, aka RGGI) and in California. Under RGGI, allowance prices traded at low values in 2013, while the cap was non-binding (Potomac Economics 2014). California policymakers consider the RPS as one of the core mechanisms to reduce GHG emissions, with cap-and-trade used to limit emissions beyond such sectoral policies (http://calcarbondash.org/). As such, at least for 2013, valuation of GHG benefits based on reduced damages is appropriate.

much lesser extent, construction-related life cycle emissions from fossil plants (see Figure 3.4). These upstream emissions savings, however, are more than offset by non-combustion life cycle emissions from the construction and—to a lesser degree—operations of RE plants. The non-combustion, life cycle impacts are not assigned to regions (and so are not included in Figure 3.3) because of the challenges of estimating the location of upstream emissions.

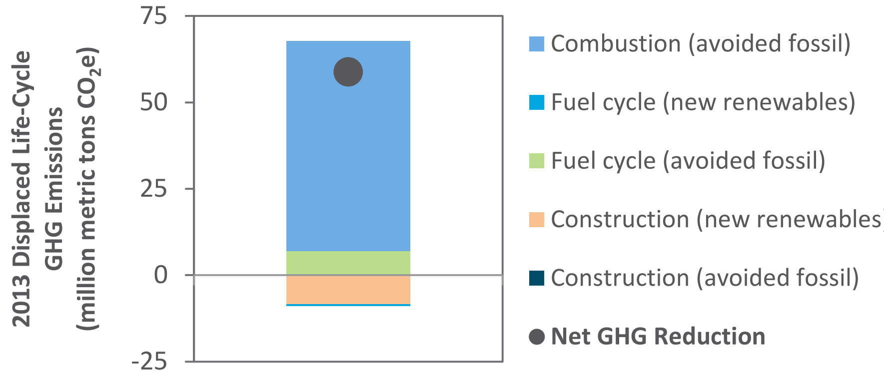

Figure 3.4. Life cycle GHG emissions impacts of RPS compliance

These GHG emissions reductions produce sizable global benefits in the form of reduced climate change damages (see Figure 3.5). Based on the IWG central-value SCC estimate, the global benefits from avoided future damages associated new RE used to meet RPS obligations in 2013 are equal to $2.2 billion. From the low to the high SCC estimates, benefits range from $0.7 billion to $3.5 billion. The higher-than-expected case accounts for the possibility of even more extreme effects, corresponding to benefits of $6.3 billion. To put these figures in another context, as also shown in Figure 3.5, the global benefits of new RE used to meet 2013 RPS obligations are equal to 2.2¢/kWh-RE, under the central-value SCC estimate. Across the full range of IWG SCC values, the global benefits of RPS compliance equal 0.7 to 6.4¢/kWh-RE.

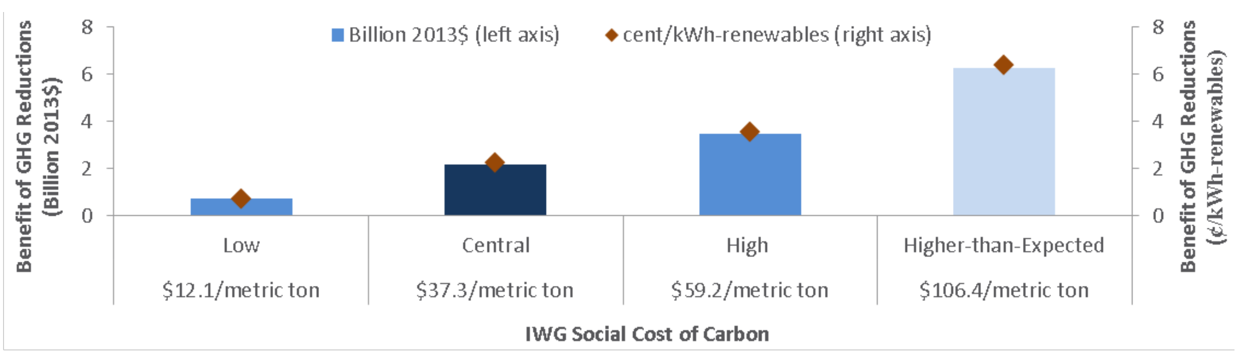

Figure 3.5. Estimated benefits of RPS compliance due to reduced global climate change damages

4. Air Pollution Emissions and Human Health and Environmental Benefits

Renewable generation used to meet 2013 RPS compliance obligations reduced national emissions of SO_2, NO_x and $PM_{2.5}$ by an estimated 77,400, 43,900, and 4,800 metric tons, respectively. These emissions reductions are estimated—across a range of approaches—to have produced \$2.6 billion to \$9.9 billion in health and environmental benefits (average of \$5.2 billion), including the prevention of 320 to 1,100 premature mortalities. The health and environmental benefits of new RE used to meet RPS requirements are equivalent to 5.3¢/kWh-RE on average, and 2.6 to 10.1¢/kWh-RE across the full range of methods. The largest health benefits accrue to the eastern half of the country, and especially in the Mid-Atlantic, Great Lakes, Northeast, and Texas, due to a combination of proximity to power sector emissions reductions and population density.

Introduction

Combusting fuels to generate electricity produces air pollutants that harm human health and cause environmental damage (NRC 2010). Epidemiological studies have shown a causal association between increased mortality and morbidity and exposure to air pollution; for examples of the association with mortality, see Dockery et al. 1993; Krewski et al. 2009; Lepeule et al. 2012. Lim et al. (2012) estimate more than three million premature deaths globally, each year, from outdoor particulate air pollution.

In the United States, a number of recent studies have evaluated the potential air quality and public health benefits of reducing combustion-based electricity generation. For example, Driscoll et al. (2015) found that policies aimed at reducing power-sector CO_2 emissions would also reduce $PM_{2.5}$ and ozone, preventing as many as 3,500 premature mortalities in 2020. Siler-Evans et al. (2013) value the health and environmental benefits of displaced conventional generation from new solar and wind power at 1¢/kWh to 10¢/kWh, with the range largely reflecting locational differences. Buonocore et al. (2015) build on this work by further exploring how benefits vary by location and technology. EPA has estimated that its CPP would provide \$14 billion to \$34 billion of monetized health benefits in 2030 based mostly on reduced premature mortality (EPA 2015e).

Though all energy sources—including RE—have environmental impacts, most RE sources have no direct, and low life cycle, air pollution emissions (IPCC 2011; Turconi et al. 2013). State-level RPS programs are therefore among the many types of policies that can be used to reduce air pollution emissions. Some previous research has found a link between RPS programs and air pollution concentrations (Eastin 2014; Werner 2014). In this section, we calculate the potential air emissions reductions associated with state RPS compliance in 2013, and present the associated public health and environmental benefits.

Methods

Our methods to value the potential air quality benefits from RPS programs involve first estimating the net reductions in direct combustion-related emissions of SO_2, NO_x, and $PM_{2.5}$ associated with new RE serving RPS compliance in 2013 (see Figure 4.1). We then quantify the public health and environmental benefits of those changes in emissions in the form of reduced mortality and morbidity, and translate those effects into monetary terms. Given uncertainty in pollutant transport, transformation, and exposure as well as uncertainty in the human response to ambient $PM_{2.5}$ and ozone exposure, we use multiple established methods to quantify the health and environmental outcomes and monetary benefits of the emissions changes. Our overall approach is similar to that used in DOE's *Wind Vision Report* (DOE 2015), and is broadly consistent with methods used in NRC (2010), Fann et al. (2012), Cullen (2013), Johnson et al.

(2013), McCubbin and Sovacool (2013), Siler-Evans et al. (2013), EPA (2015e), Novan (2014), Buonocore et al. (2015), and Driscoll et al. (2015).

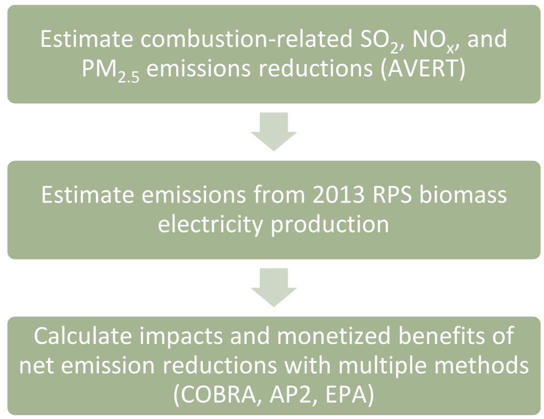

Figure 4.1. Health and environmental benefits methods overview

As the first step in this analysis, EPA's AVERT tool is used to estimate power sector SO_2, NO_x, and $PM_{2.5}$ emissions reductions from state RPS programs in 2013.[29] Those estimates consider avoided emissions due to increased renewable generation but do not include any offsetting increases in emissions associated with biomass generation used to meet RPS programs. We therefore separately estimate emissions from RPS-related biomass combustion, and subtract those amounts from the AVERT-derived estimates of reduced emissions from non-renewable generation, in order to calculate the net change in emissions.[30]

We then calculate a range of health and environmental benefits (including reduced morbidity and mortality outcomes and total monetary value) from these net emissions changes based on three different peer-reviewed approaches. Each approach accounts for pollutant transport and chemical transformation as well as population exposure and response: (1) the Air Pollution Emission Experiments and Policy analysis model (AP2, formerly APEEP, described in Muller et al. 2011), (2) EPA's benefit-per-ton methodology developed for the CPP (EPA 2015e), and (3) EPA's COBRA model (EPA 2014b). While approaches (2) and (3) both come from EPA, they differ from each other and from AP2 in multiple

[29] Although SO_2 and NO_x reductions are estimated directly in the AVERT tool, $PM_{2.5}$ reductions are not reported by AVERT. To calculate $PM_{2.5}$ reductions, we estimate emissions by plant as a function of avoided MWh generation (from AVERT) and average emissions rates (reported by Argonne National Laboratory, Cai et al. 2012; Cai et al. 2013) by generation type (coal, gas, or oil) and U.S. state.

[30] We estimate emissions for each new biomass plant used to meet RPS compliance obligations in 2013. For plants combusting bio-gas, we assume emission rates equal to state-level emission rates from natural gas plants (reported by Argonne National Laboratory, Cai et al 2012; Cai et al 2013). To estimate emissions from combustion of solid and liquid biomass, we multiply total MWh by a per-MWh emission rate for SO_2, NO_x and $PM_{2.5}$. Year 2013 emission rates for SO_2 and NO_x are directly available from EPA's Air Markets Program Data (AMPD, EPA 2015b) for a subset of the biomass plants. We use these plant-level data where available. For all biomass plants where AMPD data are not available, we assume weighted-average emissions rates of 2.3 and 0.5 lbs/MWh for NO_x and SO_2, respectively. These average emission rates were developed from all biomass plants (defined as listing biomass as their primary fuel in the 2013 AMPD data) that began operation in 1990 or later. AMPD does not provide $PM_{2.5}$ emission rates, so to estimate $PM_{2.5}$ emission rates we combine plant-level emissions from EPA's most recent, year 2011, National Emission Inventory (EPA 2015c) with generation data from AMPD for that same year; these were used to estimate plant-level $PM_{2.5}$ emissions rates, where feasible. We also developed a weighted-average emission rate for $PM_{2.5}$ in a similar manner as above, but without the 1990 cutoff due to sample size limitations. We apply this average $PM_{2.5}$ emission rate of 0.3 lbs/MWh to all biomass plants that did not have available plant-level data. A final detail: for a number of plants that reported only heat input in mmBTU but not energy generated, we use a weighted-average conversion rate of 0.07 MWh/mmBTU, based on all biomass plants that began operation after 1990 and had available data in the 2013 AMPD dataset.

respects.[31] Approaches (2) and (3) also each include two estimates of the health impacts that reflect uncertainty in the underlying epidemiological studies.[32] Henceforth, we refer to the multiple outputs from the EPA approaches as 'EPA Low' and 'EPA High' for the EPA benefit-per-ton methodology developed for the CPP and as 'COBRA Low' and 'COBRA High' for the COBRA model approach. The 'high' and 'low' classification corresponds to differences only between the underlying health impact functions employed by the particular EPA approach. We take the simple average of all five benefit estimates as the "central" value. One important assumption across all methods used is the monetary value of preventing a premature mortality (or the Value of Statistical Life, VSL). Consistent with the broader literature, all use a VSL of approximately $6 million in 2000, but updated for year 2013.[33]

Several issues related to the methodology and associated limitations, some discussed earlier, deserve note:

- Our focus is on a subset of air emissions impacts: SO_2, NO_x, and $PM_{2.5}$. We do not evaluate other potential environmental impacts, including heavy metal releases, radiological releases, waste products, land use, and water quality impacts associated with power and upstream fuel production, as well as noise, aesthetics, and others. We also only consider air emissions from power plant operations, and so do not assess upstream and downstream life cycle impacts.
- Uncertainties in $PM_{2.5}$ and biomass emissions rates are more substantial than for fossil-based SO_2 and NO_X. Because fossil-based SO_2 emission reductions dominate the benefit estimates, however, uncertainties in $PM_{2.5}$ and biomass emissions are not the largest drivers of uncertainty in the overall analysis.
- We do not fully consider the possible erosion of air quality benefits due to the increased cycling, ramping, and part loading required of fossil generators in electric systems with higher penetrations of variable renewable generation. Literature suggests that this omission will not

[31] Benefits calculated by AP2, EPA CPP, and EPA COBRA differ in a number of respects. For example, the AP2 model accounts for not only mortality and morbidity, but also air pollution induced decreases to timber and agriculture yields, visibility reductions, accelerated materials degradation, and reductions in recreation services; the benefits calculated with the EPA CPP benefit-per-ton approach and with the EPA COBRA model only include mortality and morbidity. Additionally, while the EPA CPP benefit-per-ton approach and the AP2 model both include the benefits of ozone reduction (as well as particulates), EPA COBRA includes only $PM_{2.5}$ related benefits and ignores the smaller ozone-related impacts. EPA CPP and EPA COBRA also rely on different air quality models to characterize the effects of emissions changes on ambient pollution. Finally, each approach applies a different geographic resolution in its analysis: EPA CPP benefit-per-ton is based on three large regions, whereas EPA COBRA and AP2 allow for more geographic detail in the location of the resultant benefits. Overall, each approach has advantages and limitations, and so each is treated equally when establishing a "central" (average) value.

[32] EPA Low and COBRA Low are based on research summarized in Krewski et al. (2009) and Bell et al. (2004), whereas EPA High and COBRA High are based on research presented in Lepeule et al. (2012) and Levy et al. (2005). Both sets of epidemiology research have different strengths and weakness, and EPA does not favor one result over the other.

[33] The AP2 model contains monetized benefit-per-ton estimates based on emissions in the year 2008, but based on year 2000 dollars and a year 2000 VSL value. To find 2013 benefits we updated the 2000 number for increased population exposure at the national level by multiplying the AP2 2008 values by the ratio of population in 2013 to population in 2008 (U.S. Census Bureau 2014) and then also by the ratio of the 2013 CPI to the 2000 CPI (U.S. BLS 2014). We also multiplied the AP2 value by 1.131 to adjust VSL for per-capita real income growth over 13 years. This income growth adjustment was made to mirror the EPA methodology by matching the linearized annual income change in VSL described in Table 3 of the relevant technical support document (EPA 2013a). We adjusted EPA CPP benefit-per-ton values and EPA COBRA values in a similar fashion, except, EPA benefit-per-ton values for the CPP were developed for a base year of 2020 (in 2011$) and EPA COBRA values were developed for a base year of 2017 (in 2010$). Health outcomes were also scaled by population to match year 2013, with population beyond 2013 characterized with Census projections (U.S. Census Bureau 2012).

dramatically alter the basic results reported here, especially at the relatively low levels of renewable energy penetration analyzed.[34]

- Following the earlier assumptions for GHG impacts (Section 3), we assume that landfill gas was flared prior to conversion to controlled combustion for RPS electricity generation. We do not account for any emissions changes due to this conversion, because we assume the conversion between flaring and electricity production causes only marginal differences in emissions, especially for SO_2.[35]
- Finally, our methodology presumes that SO_2 and NO_x cap-and-trade programs, such as the Clean Air Interstate Rule (CAIR), were not binding in 2013; otherwise, the benefits of RPS compliance should arguably be valued at allowance prices, to reflect savings in the cost of complying with those emissions caps (Siler-Evans et al. 2013).[36]

Results

Compliance with RPS obligations in 2013 reduced national power sector emissions of SO_2, NO_x and $PM_{2.5}$ by an estimated 77,400, 43,900, and 4,800 metric tons in 2013, respectively, with reductions in each pollutant equivalent to 2% of the corresponding total U.S. power sector emissions in 2013.

These emissions reductions are concentrated in the Midwest, Mid-Atlantic, Great Lakes, and Texas, driven by the locations of the most aggressive RPS standards but also by the regions in which higher-emitting fossil plants are displaced (see Figure 4.2). Fossil plant displacement occurs not only within RPS states but also outside of those states. A few states with biomass plants serving RPS compliance are estimated to have had small (relative to emission reductions in other states) emission increases for some of the pollutants, which is a function of the assumed emissions of those biomass plants. These emission increases do not necessarily lead to increases in state-level total pollutant exposure or related health damages, however, because reductions in other pollutant emissions or reduced transport of pollutants from neighboring states can counteract the effect of the local emission increases. In fact, the COBRA model results presented later indicate that, after taking pollutant dispersion into account, no region saw an increase in average annual $PM_{2.5}$ levels in 2013 as a result of state RPS compliance.

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[34] Though our analysis does not fully capture these effects (AVERT may capture some), results from recent research suggest that air pollutant emissions are reduced by variable renewables, even after accounting for any emissions penalties associated with plant cycling and part-loading (Oates and Jaramillo 2013; Valentino et al. 2012). Lew et al. (2013) find that accounting for impacts related to increased coal plant cycling slightly improves (by 1%–2%) the avoided NO_x emissions of wind and solar relative to the avoided emissions based on an assumption of a fully loaded plant, but that accounting for cycling impacts reduces the avoided SO_2 emissions of wind and solar by 3%–6%. A similarly detailed analysis in the Mid-Atlantic region reports more substantial emissions penalties (GE Energy Consulting 2014). In both cases, however, the impacts are not large enough to dramatically alter the basic results reported here.

[35] Kaplan et al. (2009) indicate that the range of SO_2 emission rates for landfill gas-to-energy and landfill flaring overlap and are an order of magnitude lower than the SO_2 emission rate for conventional coal power plants.

[36] Under strictly binding caps, RE does not reduce emissions per se, but instead alleviates the need to reduce emissions elsewhere in order to achieve the cap. In support of our assumption of non-binding caps, in 2013, the largest regional SO_2 and NO_x cap-and-trade program (CAIR) was non-binding (EPA 2013b; Schmalensee et al. 2013). It is possible that some more localized cap-and-trade programs were binding in 2013; however, the geographic extent of these programs was limited, so will not substantially bias our results.

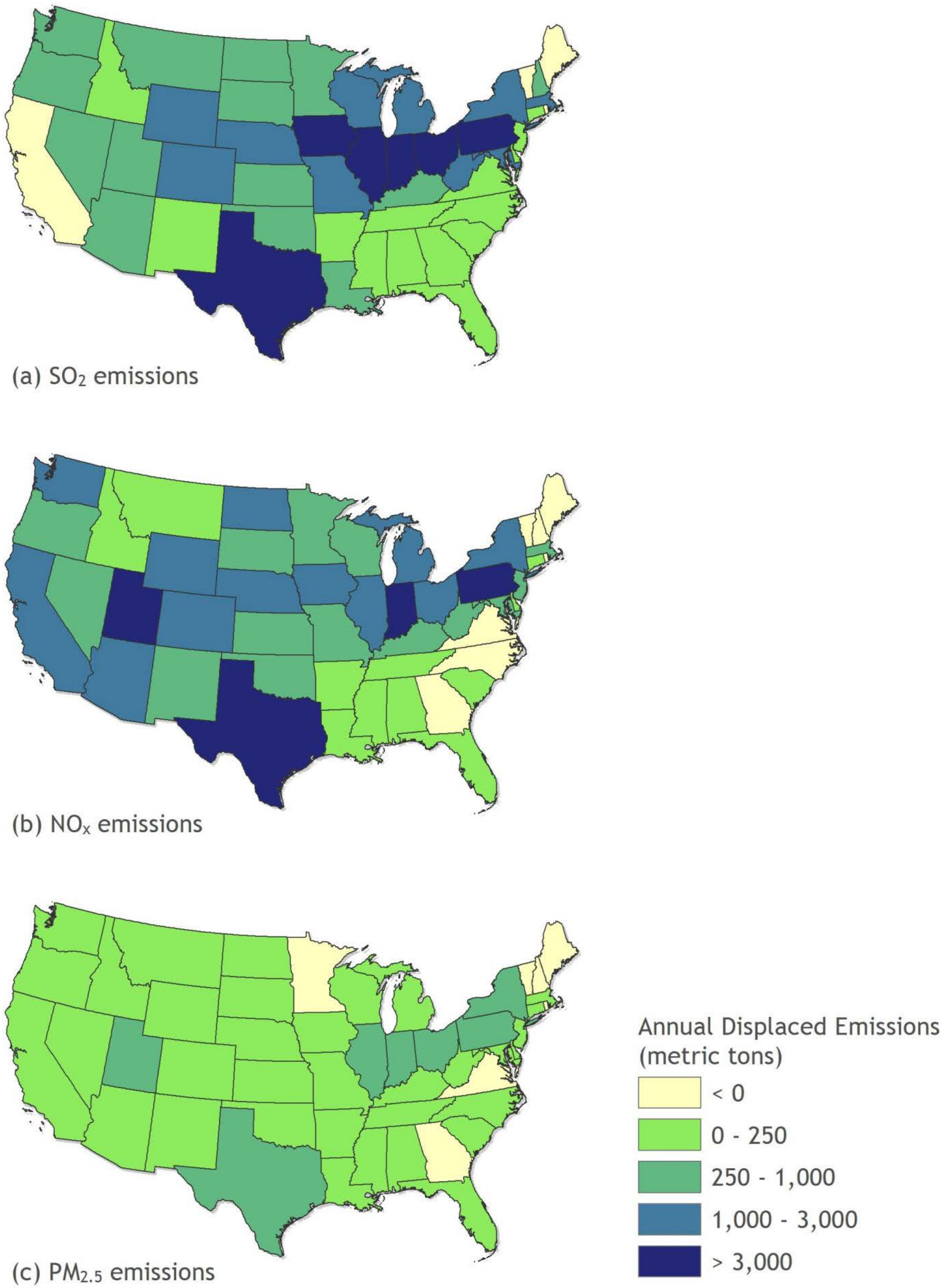
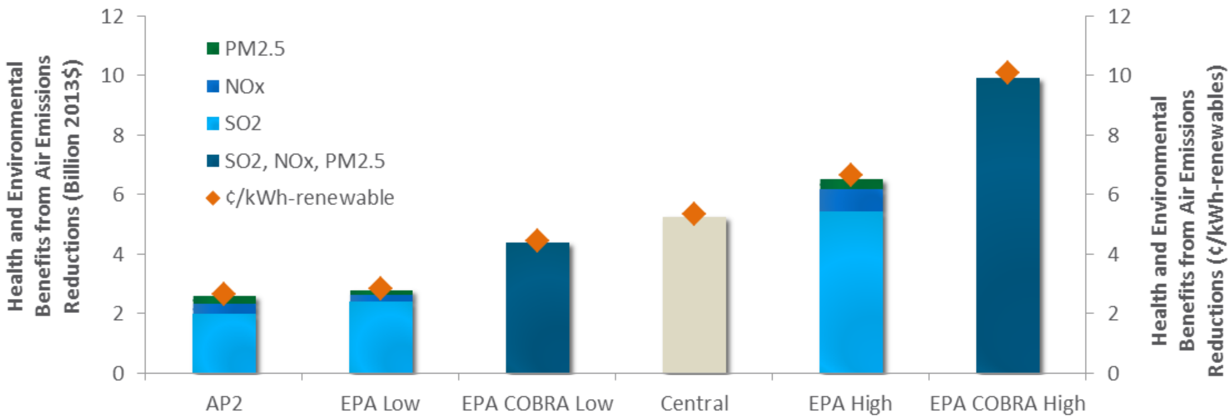


Figure 4.2. Change in emissions of (a) SO2, (b) NOx, and (c) PM2.5 from RPS compliance

These emissions reductions in 2013 led to improved air quality and health outcomes across the continental United States. Specifically, total U.S. health and environmental benefits fall in the range of \$2.6 billion to \$9.9 billion, with a “central” estimate (defined as the average of the five primary estimates) of \$5.2 billion (Figure 4.3). To put these figures in another context, as also shown in Figure 4.3, the “central” estimate is equivalent to a value of 5.3¢/kWh-RE used to meet 2013 RPS requirements. Across the total range of valuation estimates, the benefits of RPS compliance equal 2.6 to 10.1¢/kWh-RE.



Note: AP2, EPA Low and EPA High allow one to separate monetary benefits by the three specific pollutants. EPA COBRA does not allow for such segmentation. The Central estimate is a simple average of the five primary estimates.

Figure 4.3. National benefits of RPS compliance due to reduced health and environmental damages

Reduction of SO_2 (primarily from coal) and the subsequent reduction of particulate sulfate concentrations accounted for a majority of the monetized benefits (Figure 4.3). For example, SO_2 emissions reductions accounted for 77%, 86%, and 83% of the AP2, EPA Low, and EPA High benefit estimates, respectively.[37] The benefits of reduced tropospheric ozone (from reduced NO_x emissions) were relatively small, accounting for 4% and 7% of the EPA Low and EPA High benefit estimates, respectively.[38] This shows that exposure to particulates (directly or indirectly from emissions of SO_2, NO_x and $PM_{2.5}$) is the primary driver of health outcomes.

Most of the health benefits come from avoided premature mortality, primarily associated with reduced chronic exposure to ambient $PM_{2.5}$ (which largely derive from the transformation of SO_2 to sulfate particles). For example, 98% of COBRA-estimated benefits come from reduced mortality with the rest attributed to morbidity benefits. Based on the two EPA methods (and four EPA-based estimates), new RE meeting RPS programs in 2013 prevented 320–1,100 deaths that year.[39] We also estimate that RPS compliance in 2013 generated a range of benefits in the form of reduced morbidity, including avoiding between 160–290 emergency department visits for asthma, 195–310 hospital emissions for respiratory and cardiovascular symptoms, 40–560 non-fatal heart attacks,[40] and 38,000–64,000 lost work days.[41]

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[37] Benefits were not separated by pollutant with the COBRA model.

[38] An estimate of ozone benefits, separate from the total benefits, corresponding to the AP2 valuation was not available within the model.

[39] An estimate of mortality reduction corresponding to the AP2 valuation was not available within the model; similarly, AP2 does not report morbidity results.

[40] This morbidity outcome has a wide range relative to the other outcomes as it is estimated based on two different studies, reflecting the uncertainty related to this outcome.

The benefits reported here are net of emissions from biomass electricity used for RPS compliance. We estimated emissions of 1,800, 6,200, and 900 metric tons of SO_2, NO_x, and $PM_{2.5}$, respectively, from new biomass meeting RPS requirements in 2013. Biomass electricity therefore reduced total RPS emissions benefits by 2.3%, 12.3%, and 15.8% for SO_2, NO_x, and $PM_{2.5}$, respectively. Because health benefits are dominated by SO_2 reductions, the biomass emissions only marginally reduce total monetized benefits; for example, the EPA Low value would have been 4% larger without the biomass emissions.

Finally, the largest benefits accrue to the eastern half of the country, and especially in the Mid-Atlantic, Great Lakes, Northeast, and Texas. As one example, Figure 4.4 illustrates the regional allocation of monetized benefits from fine particulate exposure calculated using the COBRA Low approach.[42]

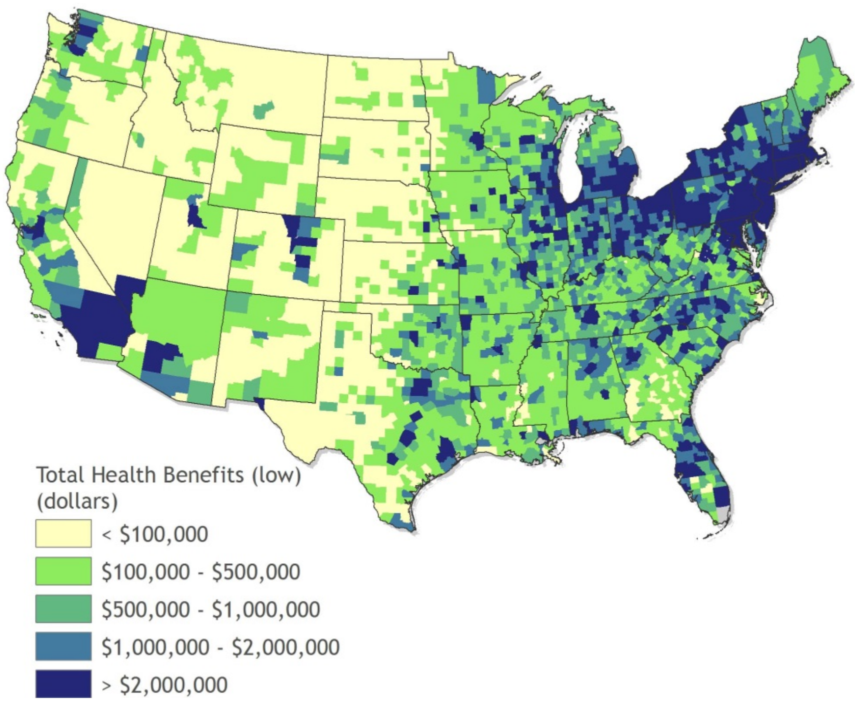


Figure 4.4. Regional benefits of RPS compliance due to reduced health and environmental damages from particulate matter under the 'COBRA Low' estimates

[41] Other morbidity benefits: RE serving RPS programs in 2013 was also estimated to avoid between 440 – 730 incidents of acute bronchitis (ages 8-12), 5,700 – 9,400 incidents of lower respiratory symptoms (ages 7-14), 8,200 – 14,000 incidents of upper respiratory symptoms (in asthmatics age 9-11), 225,000 – 380,000 minor restricted-activity days, and 14,000 – 20,000 incidents of asthma exacerbation (age 6-18). Additionally, we estimated that NO_x emission reductions associated with RPS compliance reduced ozone levels and thus avoided 80 respiratory related hospital admissions, 30 emergency room visits due to respiratory symptoms, 20,000 school loss days, and 58,000 incidents of acute respiratory symptoms. Note that the COBRA model does not produce estimates of ozone air quality and thus only a single value for the ozone impacts is presented, based on EPA CPP benefit-per-ton estimates.

[42] These monetized benefits (based on the COBRA Low results) focus exclusively on fine particulates. Ozone is also found to be reduced in many locations, but is not accounted for in the COBRA model used to generate this figure. The monetized benefits from ozone reductions are of second order compared to the benefits of $PM_{2.5}$ reductions, however, so the exclusion of ozone in the figure does not create substantial bias. The EPA CPP benefit-per-ton approach and APP model do not output the locations of the resultant benefits, so are now shown here.

5. Water Use Reduction Benefits

Renewable generation used to meet 2013 RPS compliance obligations reduced national water withdrawals and consumption by an estimated 830 billion gallons and 27 billion gallons, respectively. These power-sector water use reductions are equivalent to savings of 8,420 gallons of withdrawal and 270 gallons of consumption with each MWh of generation of renewable electricity. Water use reductions vary seasonally and come predominantly from freshwater sources, with reductions varying regionally due to geographic differences in power plant fuel types and cooling system configurations. The largest withdrawal and consumption reductions were in California and Texas, respectively, demonstrating the important benefits RPS compliance can have in water-stressed regions.

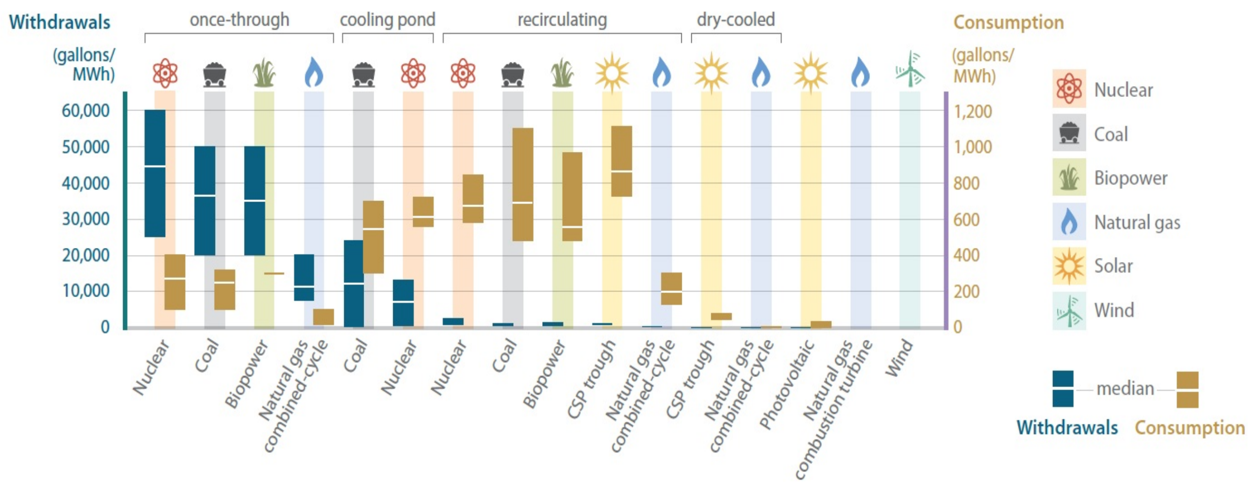
Introduction

The electric sector is heavily dependent on water—primarily for thermal plant cooling—and can affect water resources through water withdrawals, water consumption, changes in water quality, and changes in water temperature. 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 (Kenny et al. 2009). The U.S. electric sector is the largest withdrawer of water (38% of total) in the nation (Maupin et al. 2014), whereas its share of consumption is much lower, around 3% (Solley et al. 1998). As such, water availability impacts the electric system, including impacts on new capacity decisions (Macknick et al. 2015) and on power plant operations and reliability (DOE 2014; Rogers et al. 2013). In turn, water availability and quality for other competing uses are impacted by the electricity sector. Moreover, future uncertainties with regard to water availability and temperature, including those associated with climate change, may further exacerbate vulnerabilities in the electric sector (Cohen et al. 2014; DOE 2014).

Many RE technologies have low water withdrawal and consumption intensities compared to fossil and nuclear generating technologies, whether only considering operational demands (see Figure 5.1) or the entire life cycle (Macknick et al. 2012a; Meldrum et al. 2013). Prior studies have evaluated the impact of a wide range of U.S. electricity sector futures on water demands (Arent et al. 2014; Chandel et al. 2011; Clemmer et al. 2013; DOE 2015; Macknick et al. 2012b; Roy et al. 2012; Tidwell et al. 2013a; van Vliet et al. 2012). This body of work generally finds that scenarios designed to meet carbon reduction goals would also result in water savings, particularly when renewable-based pathways are followed (Clemmer et al. 2013; Macknick et al. 2012b).[43]

While the literature contains a substantial amount of scenario analysis of water use by the U.S. power sector, no studies have quantified—on a national scale—the potential water benefits that have resulted from RPS mandates. RPS programs are generally not designed around water reduction goals, though water savings could be a significant co-benefit in some regions. In this section, we calculate the water withdrawal and consumption impacts of RPS compliance, providing insights on regional and temporal dynamics.

[43] Recently, the DOE *Wind Vision Report* (DOE 2015) demonstrated how achieving 35% wind penetration by 2050 could result in water consumption savings of 23% over a scenario with wind capacity held constant at 2013 levels (DOE 2015).



Note: Geothermal technologies are not displayed in the figure due to the multiple configurations (e.g., binary, flash) and cooling system types (e.g., wet, dry, hybrid) commonly utilized, but water withdrawal and consumption impacts are calculated in this analysis for geothermal technology configurations based on data reported in Macknick et al. (2012b).

Figure 5.1. Summary of operational water withdrawal and consumption requirements of electricity generation technologies by technology and cooling system

(Source: Averyt et al. 2011)

Methods

Our methods to assess potential water withdrawal and consumption benefits from state RPS programs involve first estimating the quantity and type of renewable generation used to serve RPS compliance obligations in 2013 along with the associated reductions in fossil-based generation (using AVERT), and then estimating both water use reductions from displaced fossil-based generation as well as increased water use from RPS resources (see Figure 5.2). This approach builds on established methods for assigning generation from individual electric generating units or aggregate regional generation to corresponding cooling system types (Averyt et al. 2013; UCS 2012) that have been applied in multiple studies evaluating national and regional water impacts of the U.S. electricity sector (Clemmer et al. 2013; DOE 2015; Macknick et al. 2012b; Macknick et al. 2015; Rogers et al. 2013).[44]

Water withdrawal and consumption impacts from changes in fossil generation are calculated by applying fuel/prime mover/cooling system-specific water intensity rates (in gallons per MWh of electricity generated) to generating unit-level changes in monthly generation, as estimated with AVERT. A similar process is used to calculate increases in water use resulting from renewable electricity technologies, inclusive of all operational water demands (e.g., cooling in the case of biomass, module cleaning in the case of PV). Water intensity rates are based on a literature review of nationally applicable estimates of

[44] We start with the unit-specific outputs from AVERT model for fossil generation displaced by new RE for RPS compliance in 2013 (Section 2). To match AVERT generators with cooling system characteristics, we make an initial assignment based on the Office of Regulatory Information Systems Plant Location (ORISPL) Plant ID number, which is included in the AVERT outputs, as well as the UCS EW3 Energy-Water Database (UCS 2012), with updates from Ventyx (2013). From this preliminary matching of power plants, we assign prime mover technology, cooling system technology, and water type (freshwater or saline water) to each AVERT generating unit based on matches of nameplate capacity. Additional details can be found in Averyt et al. (2013). For cases in which there is no obvious match, prime mover types and cooling systems are assigned based on similar generators within the same power plant or via internet research. For cases in which this procedure did not lead to new information (for a total of 20 generating units with 437 MW of capacity), no cooling systems are assigned.

power plant water use (Macknick et al. 2012b). Water use increases and decreases are aggregated, with results summarized on a net basis nationally, by month, and by state.

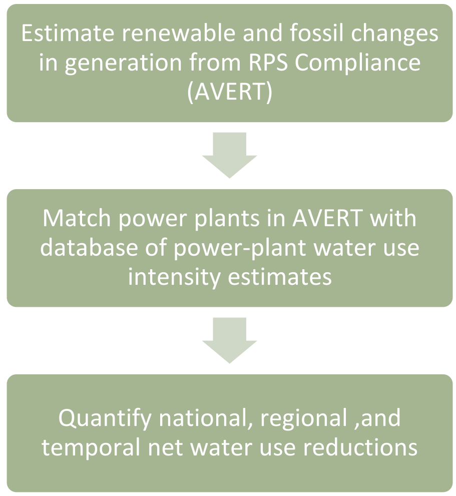


Figure 5.2. Water use benefits methods overview

Several issues related to the methodology and associated limitations, some discussed earlier, deserve note:

- We consider only the operational water requirements of the power sector and do not estimate full life cycle water uses, including upstream processes and fuel sources. Including effects on upstream water requirements would likely increase the overall water savings from RPS resources, but associating upstream water uses to regions would be challenging and introduce greater uncertainty to our regional results. Moreover, prior work has demonstrated that operational water requirements are more than an order of magnitude greater than the combined water requirements of other life cycle stages, so this exclusion does not substantially alter our results (Meldrum et al. 2013).
- The assessment of operational water use impacts relies on assumptions about which prime mover technology type and cooling system are associated with individual generators. In practice, individual generators at a specific power plant might be associated with multiple cooling system types, with substantially varying water use intensities. We use methods described in Averyt et al. (2013) to associate individual generating units with cooling systems.
- Biomass generating units have many different configurations that affect water use. We categorize biomass plants into three broad categories: biomass (non-gas), biomass (gas), and landfill gas. Biomass (non-gas) sources are assigned water use characteristics of simple-cycle steam turbine solid-biomass power plants, biomass (gas) sources are assigned water use characteristics of biogas-based power plants, and landfill gas plants are assumed to require no water for operations, per values in Macknick et al. (2012).
- We do not consider any hydropower-related evaporation in this analysis due to uncertainties in allocation of evaporative consumption among multiple uses of reservoirs, such as flood control, drinking supply, and recreation, in addition to the inherent variability in evaporation rates with reservoir and local climate characteristics. Given the small amount of incremental hydropower serving RPS standards, and the fact that most of those facilities are run-of-river, this assumption is unlikely to be a major driver of uncertainty or bias.

- Finally, we do not quantify the benefits of water use reductions in monetary terms due to challenges associated with quantifying the value of water resource services (DOE 2015).

Results

New RE used for RPS obligations in 2013 reduced net national water withdrawals by an estimated 830 billion gallons and net national water consumption by 27 billion gallons (see Figure 5.3). These reductions both amount to 2% of the corresponding power sector totals for 2013. Each MWh of electricity generated for RPS compliance obligations in 2013 represents an average savings of 8,420 gallons of water withdrawal and 270 gallons of water consumption.

Additional withdrawal needs from new RPS generation are less than 1% of the withdrawal reductions from decreased fossil-based generation. This result is largely because fossil-based generators that use once-through cooling systems have high water withdrawal intensity, and renewable generators typically do not use once-through cooling (with exceptions for some biomass-based systems). Additional consumption needs from RPS-compliant new renewable generation are equal to 15% of water consumption reductions associated with displaced fossil-based generation. This higher percentage of water consumption from RPS-compliant generation, as compared with that for withdrawals, is largely a result of the water use characteristics of displaced fossil-based generation, which have relatively low water consumption rates and relatively higher water withdrawal rates. In addition, some biomass, CSP, and geothermal technology configurations that use recirculating cooling systems similar to those used by fossil-based generators can have water consumption rates similar to the displaced fossil generators. Notwithstanding the fact that water use by renewable generators somewhat offsets water use reductions from displaced fossil generation, the net effect is positive, as shown in Figure 5.3.

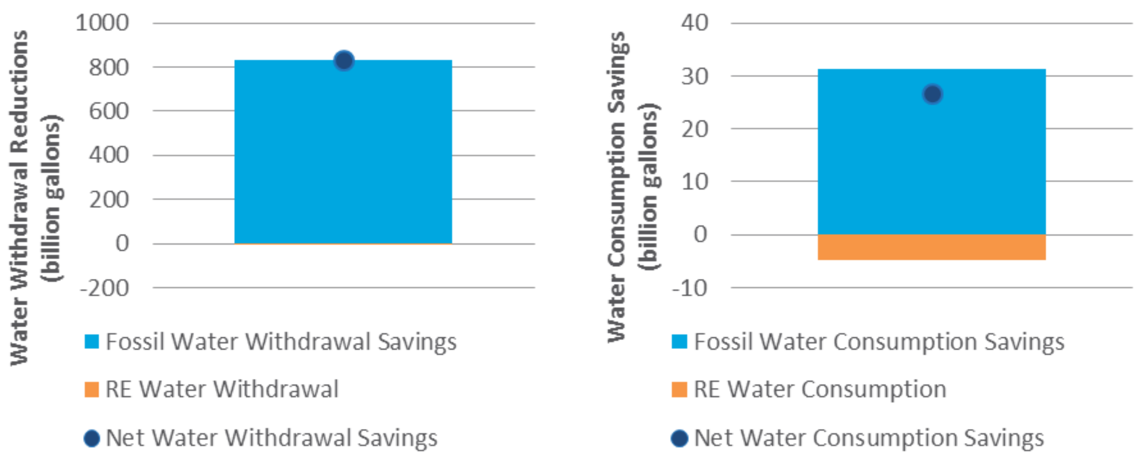


Figure 5.3. National water withdrawal (left) and consumption (right) benefits of RPS compliance

Figure 5.4 highlights monthly trends in net water withdrawal and consumption savings. The highest levels of water savings occur in October through May, while July and August represent the lowest levels of water savings. Summer savings are lower because renewable generation in these months often displaces less water-intensive technologies (e.g., natural gas combustion turbine) and because some renewable technologies with higher water intensities (e.g., CSP) produce more electricity in the summer.

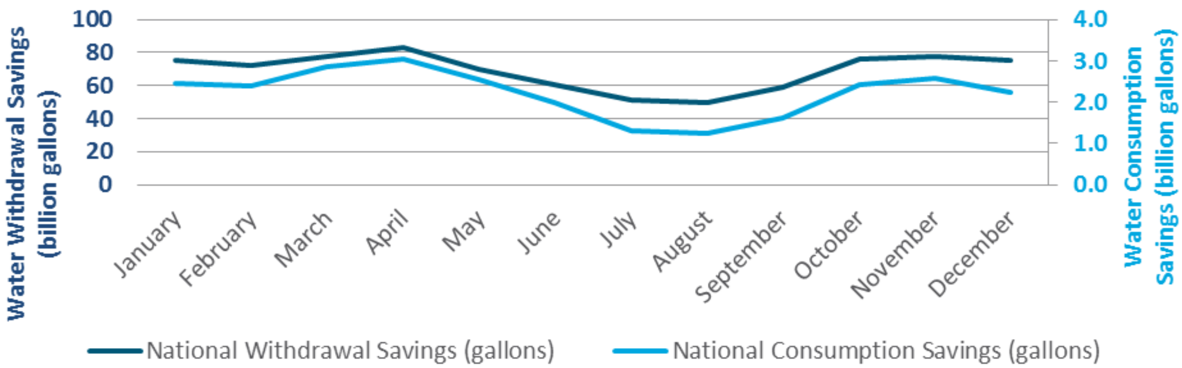


Figure 5.4. National water withdrawal and consumption benefits of RPS Compliance, by month

Water withdrawal and consumption savings are not uniform throughout the continental United States (Figures 5.5 and 5.6). Moreover, because fossil plant displacement and RPS generation occur not only in RPS states but also outside of those states, water benefits extend beyond the 29 states and Washington, D.C. with RPS compliance obligations in 2013. Most states are estimated to have seen decreases in both withdrawal and consumption in 2013. Importantly, there are reductions in water use in many drought-prone regions (e.g., California, Texas, and parts of the southwest), with the largest withdrawal savings in California, and the largest consumption savings in Texas.

Certain states experience large withdrawal savings but lower consumption savings (e.g., New York), whereas others experience lower withdrawal savings but larger consumption savings (e.g., Pennsylvania). This regional variation reflects the type of generators and cooling systems being displaced and the water requirements of local renewable technologies deployed. Six states experienced slight net increases in water consumption: Maine, New Hampshire, North Carolina, Nevada, Virginia, and Vermont. For Nevada, water consumption requirements of new geothermal facilities outweighed the water consumption savings at displaced coal- and gas-fired generators. For the five other states with an increase in net water consumption, the assumed water consumption requirements of biomass-fired technologies were greater than the water consumption savings of the displaced fossil technologies. Only one state (Vermont, which did not have an RPS in 2013) experienced a slight increase in water withdrawals, the result of in-state biomass projects serving RPS demands in other states.

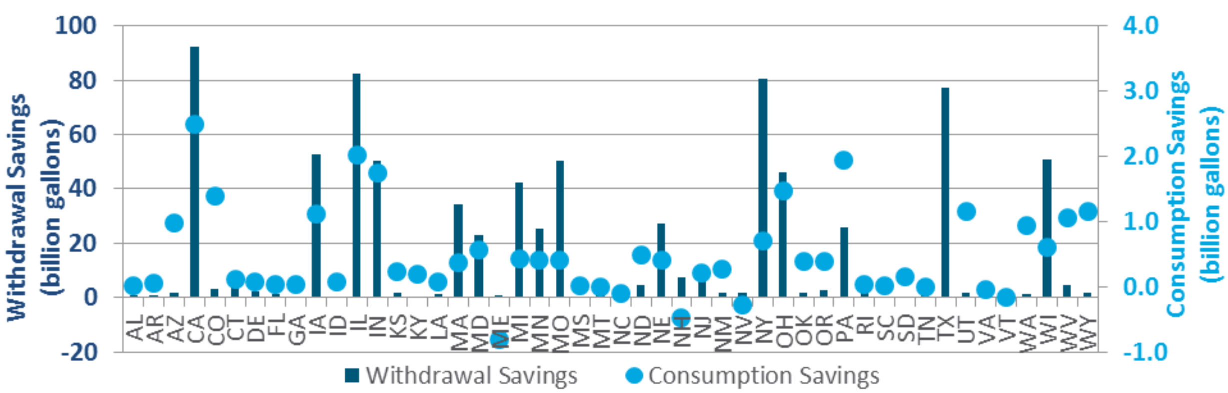
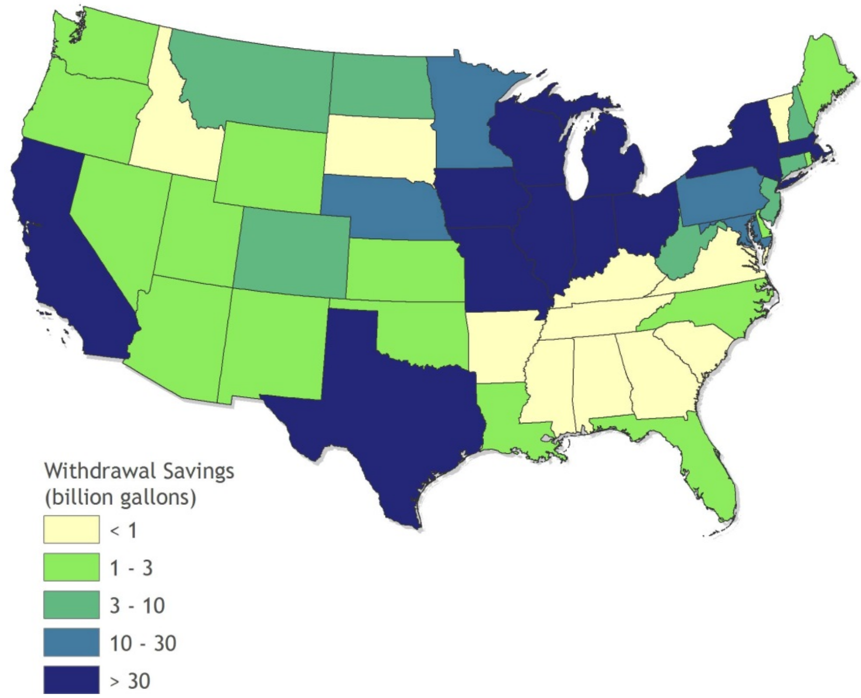


Figure 5.5. Water withdrawal and consumption benefits of RPS compliance, by state

(a) Water withdrawal benefits



(b) Water consumption benefits

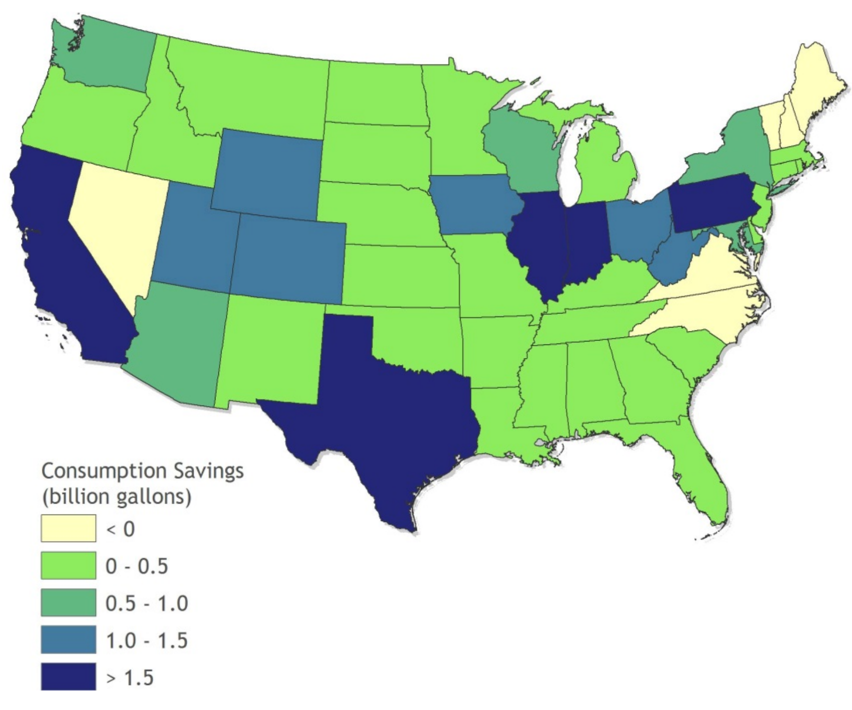


Figure 5.6. Regional variation of water withdrawal and consumption benefits of RPS compliance

We estimate reductions of both freshwater and saline water demands resulting associated with RPS policies: 82% of the withdrawal reductions and 97% of the consumption reductions were from freshwater sources. Saline water savings were concentrated in California, Connecticut, Florida, New York, and Texas. Figure 5.7 highlights estimated water savings in just these five states, showing the split between fresh and saline water savings. Most water consumption savings in even these states come from freshwater sources. However, withdrawal savings consist primarily of saline water in California, Connecticut, and Massachusetts due to the types and the coastal location of generators in those states. Reducing saline water withdrawals can have important impacts for the health of marine ecosystems (EPA 2011).

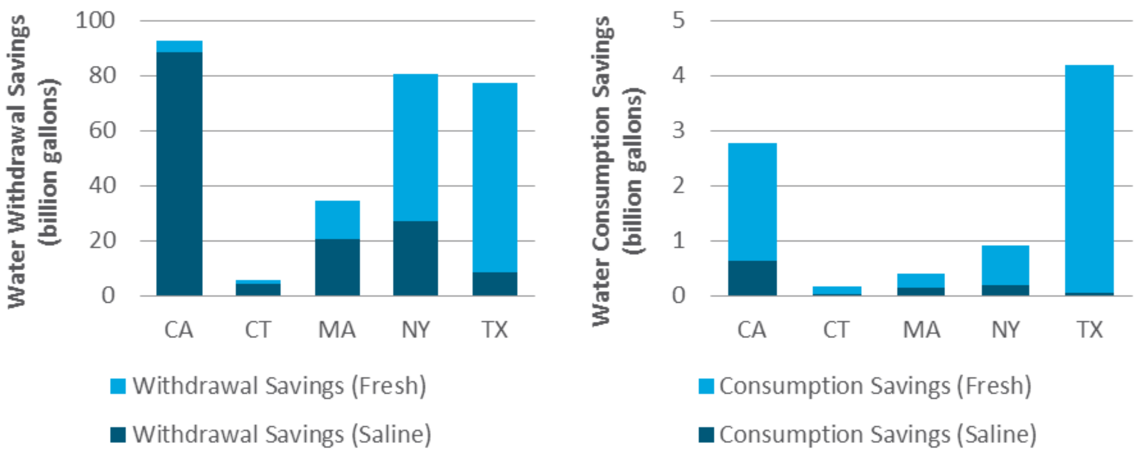


Figure 5.7. Fresh and saline water withdrawal (left) and consumption (right) benefits of RPS compliance

Though standard methods do not exist to value—in monetary terms—these water use impacts, water use reductions from RPS policies can be considered a benefit, especially where water is scarce. Reductions in water demands also reduce the vulnerability of electricity supply to the availability or temperature of water, potentially avoiding electric-sector reliability events and/or the effects of reduced thermal plant efficiencies—concerns that might otherwise grow as the climate changes (DOE 2014). Reduced power-sector water use also frees water for other uses, whether for other productive purposes (e.g., agricultural, industrial, or municipal use) or to strengthen local ecosystems (e.g., benefiting wildlife owing to greater water availability, lack of temperature change, etc.). Finally, by avoiding upstream water demands from fossil fuel supply, RE may help alleviate other energy-sector impacts on water resource quality and quantity, e.g., water otherwise used in mining, coal washing, and hydraulic fracturing (Averyt et al. 2011).

6. Gross Jobs and Economic Development Impacts

Renewable generation used to meet 2013 RPS compliance obligations, along with average annual RPS-related capacity additions in 2013 and 2014, supported an estimated 200,000 U.S.-based gross jobs earning average annual salaries of $60,000, and driving over $20 billion in GDP. Of these gross jobs, over 30,000 are related to ongoing operations and maintenance (O&M) while the remaining 170,000 are supported by construction activity. Labor-intensive PV installations account for the majority of construction jobs, while established wind plants account for the majority of O&M jobs. California had the most significant renewable capacity expansion and generation associated with RPS compliance obligations, and thus also had more "onsite" renewable energy jobs (i.e., installers, construction workers, plant operators, and other maintenance personnel) than any other state in 2013.

Introduction

Renewable electricity generation infrastructure requires workers and expenditures. These include onsite personnel performing construction and O&M work, as well as workers across the country (and worldwide) in manufacturing, business services, and other aspects of the energy supply chain. Workers, in turn, spend money that further supports jobs and other economic activity. The physical location of supply chain impacts—and related induced impacts—are, of course, greatly affected by where materials, manufacturing, and business services occur, whether domestic or international in origin.

Much research has sought to quantify the gross and net impacts of RE deployment on jobs and economic development (e.g., Böhringer et al. 2012; Böhringer et al. 2013; Breitschopf et al. 2011; Brown et al. 2012; Chien and Hu 2008; Frondel et al. 2010; Haerer and Pratson 2015; Hillebrand et al. 2006; Lehr et al. 2008; Lehr et al. 2012; Marques and Fuinhas 2012; Menegaki 2011; Meyer and Sommer 2014; Wei et al. 2010). This literature typically finds that RE deployment does increase gross jobs in and related to the RE sector. At the same time, the evidence and economic underpinnings for any "net" impacts on jobs or economic development are limited, because RE directly displaces demand for other sources of electric generation, impacting employment and economic development associated with those sectors. Additionally, to the extent that RE deployment 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 on a global or even national level (e.g., Rivers 2013). Moreover, even if net positive effects occur, which is possible at the local or state level, questions remain as to whether such effects serve as strong economic justification for government policy (e.g., Borenstein 2012; Edenhofer et al. 2013; Gillingham and Sweney 2010; Morris et al. 2012).

These considerations notwithstanding, state RPS policies have been motivated in part by potential local economic development and employment impacts (Rabe 2008). Previous research has sought to establish a statistical link between state RPS programs and jobs, but has found mixed results (Bowen et al. 2013; Yi 2013). In this section, we estimate the potential gross, domestic jobs and other economic impacts supported by RPS policies. Such estimates may provide governments, stakeholders, and other interested parties valuable information about how RE expenditures translate to gross jobs, gross domestic product (GDP), earnings, and economic activity in the United States. At the same time, it must be emphasized that our analysis does not include an assessment of economy-wide net impacts,[45] and we therefore make no claim of net economy-wide benefits or costs. For this reason, we refer to the jobs and economic effects as *impacts* rather than *benefits*.

[45] The JEDI and IMPLAN models used in this analysis do not represent a full spectrum of economic impacts that could arise as a result of renewable electricity generation, and therefore do not allow for a comprehensive assessment of net effects.

METHODS

As shown in Figure 6.1, the first step in the analysis is to identify new RE generation used to meet RPS compliance obligations in 2013 and RE capacity built over the 2013 and 2014 period to serve RPS requirements (see Section 2). We then rely primarily on NREL's Jobs and Economic Development Impacts (JEDI) suite of models to estimate the gross jobs and economic development impacts of RPS-related RE projects in 2013. Specifically, we use JEDI models for wind, solar, geothermal, hydropower, and biomass. A JEDI model does not exist for landfill gas, so IMPLAN—a proprietary input-output (I-O) model—is used instead, with landfill gas expenditure cost distributions from Jensen et al. (2010). Both JEDI and IMPLAN have been commonly used for the type of analysis conducted here (e.g., Adelaja and Hailu 2008; Bamufleh et al. 2013; Croucher 2012; DOE 2015; Navigant 2013; Slattery et al. 2011; You et al. 2012). The methodologies employed by the two models are broadly consistent and use the same set of economic multipliers. Costs and assumptions for the "domestic content" for all renewable technologies other than landfill gas are based on JEDI default data.[46]

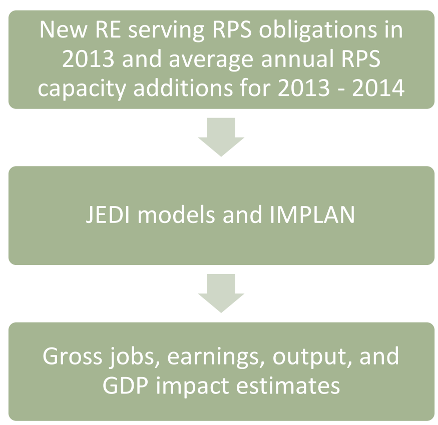


Figure 6.1. Economic development impacts methods overview

JEDI produces impact estimates for four metrics: gross jobs, earnings, output, and GDP.

- Jobs are expressed as full time equivalent (FTE). One FTE is the equivalent of one person working 40 hours per week for one year.[47]
- Earnings include wages, salaries, and employer-provided supplements such as health insurance and retirement contributions.

[46] Default data are used to ensure that each technology is treated as similarly as possible to maintain consistency. JEDI default costs come from interviews with project developers, operators, consultants, engineers, and others familiar with construction, installation, and operation of different types of energy projects. 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). That said, JEDI default costs are based primarily on actual projects, with some lag. As such, rapid changes in—for example—prices for solar PV installations could merit adjusting these defaults to reflect actual 2013 projects. Solar PV costs have decreased below JEDI defaults and, as of this publication, continue to decline. A primary driver for PV price declines through 2013, however, was module prices (BNEF 2015). JEDI does not, by default, include the impacts from module manufacturing in its estimates, however, as JEDI assumes that this manufacturing occurs outside of the United States. As such, while our use of default values for PV in 2013 may impose some error, the size of that error would not likely have a dramatic effect on the results.

[47] Two workers who work 20 hours per week, for example, would be reported as a single FTE.

- Output is a measure of overall economic activity. At an individual business, it could be thought of as revenue. This revenue would include payments for inputs as well as payroll, taxes, and property type payments (including profits).
- GDP is solely a measure of the value of production. It includes payments to workers, property type income, and taxes.[48]

JEDI reports these four metrics in 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 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, JEDI reports domestic jobs and impacts.

We use JEDI and IMPLAN to estimate domestic jobs and economic development impacts associated with both the operation and construction (including manufacturing of equipment subsequently installed) of RE facilities used to support state RPS programs. Operational impacts are based on RE facilities used to meet RPS compliance obligations in 2013, while construction impacts are based on average annual RPS capacity additions in 2013 and 2014; both sets of assumptions are described in Section 2. Average annual additions from 2013 through 2014 are used for the construction-related impacts in order to mitigate variability in RE capacity build rates from year to year, and also to reflect the fact that construction-related jobs and economic impacts occurring in 2013 may be associated partly with projects completed in the following year, given lags between manufacturing, construction, and commercial operations.

All results produced by JEDI and IMPLAN are for the equivalent of a single year; although O&M jobs can be assumed to be ongoing, construction-related jobs are inherently of limited duration. Results are reported on a national and, for onsite jobs only, state-by-state basis.[49]

Two issues related to the methodology and associated limitations, both noted earlier, deserve reiteration:

- Our estimates represent gross impacts. JEDI and IMPLAN results represent the workforce needs and economic impacts that could feasibly have been supported by the construction and operation of RPS-related renewable generation facilities; they do not reflect other potential economic impacts of an RPS, such as those resulting from displaced fossil generation or capacity, changes in utility electricity rates, or changes in property values or other prices. As such, the results should not be considered net economy-wide impacts or societal benefits.
- Several aspects of the methodology may produce uncertainty or inconsistency in the results. For example, landfill gas is treated somewhat differently than the remaining technologies, and we assume that average construction over the 2013-2014 period influences construction-related jobs in 2013. Additionally, we use default JEDI data and assumptions to estimate impacts, which does not provide perfect cost information for all projects. Any uncertainty created by these or other factors may be more significant for state-level, as opposed to national, results.

[48] GDP is also known as value added, which is how it is labeled in the JEDI model. Property type income is also known as gross operating surplus or simply "capital."

[49] We do not estimate supply chain or induced economic impacts by state because of uncertainty relating to where in the United States those impacts occur. A solar installer in New Jersey, for example, may purchase IT services from a company in California but could just as easily purchase these services from a company in another state.

Results

We estimate that new RE serving state RPS policies supported nearly 200,000 gross domestic jobs in 2013 (Figure 6.2), each earning an average annual salary of $60,000, with RE expenditures driving over $20 billion in gross GDP in the United States (Table 6.1). Of the total gross domestic jobs in 2013, the vast majority—nearly 170,000—are associated with construction of new facilities, with the remaining 30,000 associated with operation of renewable projects serving RPS compliance obligations in 2013. Most gross jobs are either onsite or within the supply chain, with a smaller number of induced jobs, reflecting the predominance of jobs tied to construction of new facilities. Similar trends are also apparent when comparing gross GDP impacts between construction-related and O&M activities, and among onsite, supply chain, and induced jobs (Table 6.1).

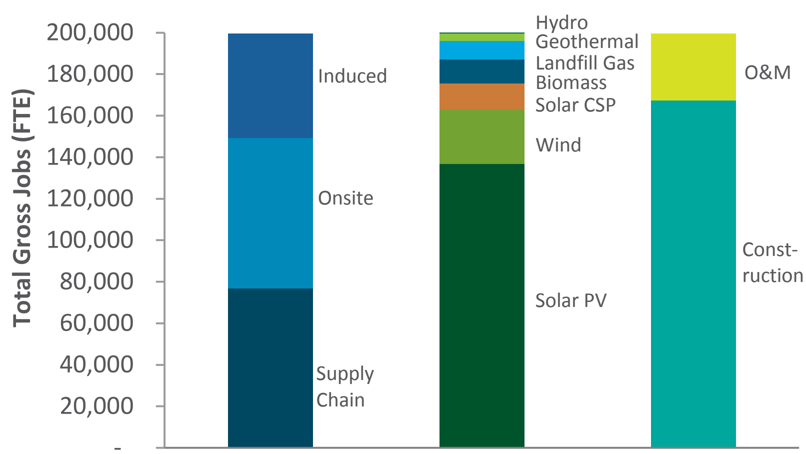


Figure 6.2. Estimated total gross domestic jobs from RPS compliance

Table 6.1. Estimated gross domestic jobs and economic impacts from RPS compliance

	Jobs (FTE)	Total Earnings (Million $2013)	Annual Earnings Per FTE ($2013)	Output (Million $2013)	GDP (Million $2013)
Construction					
Onsite	67,000	$4,500	$67,000	$7,100	$6,000
Supply Chain	62,700	$3,800	$60,000	$10,500	$6,200
Induced	37,700	$1,700	$46,000	$5,100	$3,000
Sub-Total	*167,400*	*$10,000*	*$60,000*	*$22,700*	*$15,200*
O&M					
Onsite	5,700	$400	$70,000	$570	$450
Supply Chain	14,000	$840	$60,000	$5,260	$3,340
Induced	12,500	$670	$53,000	$2,020	$1,180
Sub-Total	*32,200*	*$1,910*	*$59,000*	*$7,840*	*$4,970*
Total Construction + O&M					
Onsite	72,700	$4,900	$67,000	$7,670	$6,450
Supply Chain	76,700	$4,640	$60,000	$15,760	$9,540
Induced	50,200	$2,370	$47,000	$7,120	$4,180
Total	**199,600**	**$11,910**	**$60,000**	**$30,540**	**$20,170**

Note: Totals may not sum due to rounding. Similarly, average annual earnings may not divide precisely due to rounding

The distribution of jobs among renewable technologies reflects both the contribution of each technology to RPS generation and capacity additions, as well as the labor-intensity of their construction and operation phases. As such, solar PV—including both rooftop and utility-scale—accounted for the lion's share of construction jobs in 2013 (left-hand panel in Figure 6.3), driven by its large fractional share of recent RPS capacity additions (as shown earlier in Section 2)[50] and the relatively high labor intensity of the installation and construction process (especially for rooftop solar). Of the total PV-induced construction jobs, 62% are associated with rooftop applications (compared to 38% from utility-scale PV systems), despite the fact that rooftop installations accounted for just 26% of the underlying RPS-related PV capacity additions. In contrast, when focusing on the operations phase (right-hand panel in Figure 6.3), wind energy supported the largest portion of O&M jobs in 2013, followed by landfill gas, biomass, and geothermal. During O&M, PV installations supported a disproportionately small fraction of jobs (4%, compared to PV's 6% share of RPS generation in 2013) due to the low labor intensity of O&M.

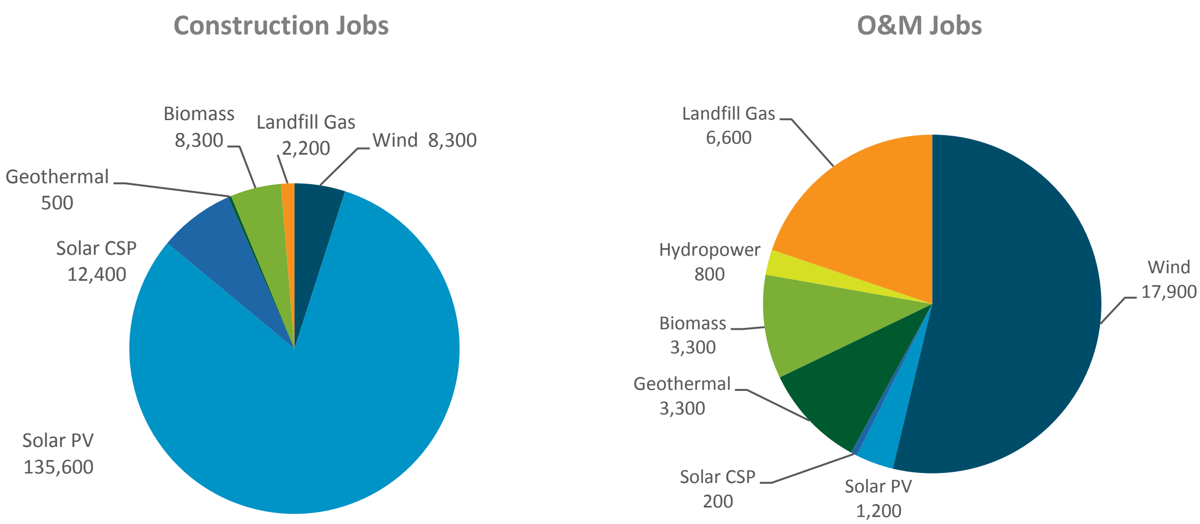


Figure 6.3. Gross domestic construction and O&M jobs from RPS compliance, by technology

Of the three categories of jobs—onsite, supply chain, and induced—only onsite jobs can be readily linked to specific states. The distribution of onsite jobs (including those associated with both construction and O&M) across states largely corresponds to the distribution in RPS capacity additions, given the dominance of construction-related jobs (see Figure 6.4). In particular, nearly 50% of RPS capacity additions in 2013 through 2014—primarily PV—was built in California, as shown earlier in Section 2. Correspondingly, most onsite job impacts from construction activities occurred in California, followed by Arizona, North Carolina, and Massachusetts. California also led states in RPS-related onsite O&M jobs in 2013, followed by New Jersey and New York.

[50] In earlier years, wind would have been the largest source of construction jobs, given its historical dominance among new RPS capacity additions (Barbose 2015).

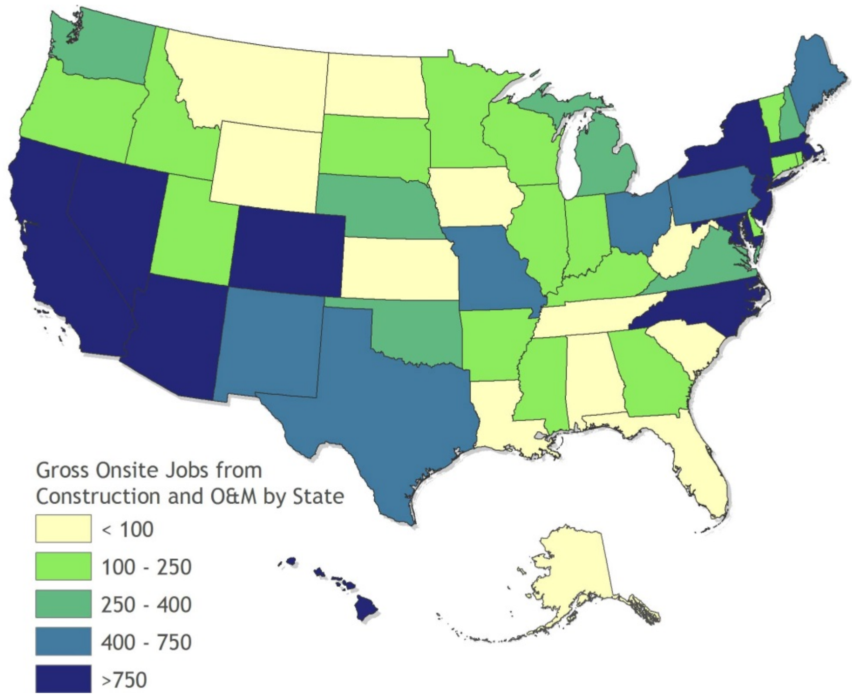


Figure 6.4. Gross onsite jobs from construction and O&M from RPS compliance, by state

7. Wholesale Electricity Price Reduction Impacts

Renewable generation used to meet 2013 RPS compliance obligations potentially shifted the supply curve for electric power, reducing wholesale electricity prices and yielding an estimated $0 to $1.2 billion in savings to electricity consumers across the United States. These consumer savings are equivalent to 0.0 to 1.2¢/kWh-RE. The wide range of estimates reflects bounding assumptions about how the effects of renewable generation on wholesale spot market prices decline over time and the extent to which consumers are exposed to those prices. Importantly, these impacts are best considered wealth transfers from owners or shareholders of electricity generating companies to electricity consumers rather than net societal benefits.

Introduction

RE generation with low marginal costs pushes out the wholesale power supply curve, an impact sometimes referred to as the "merit-order effect" (Sensfuß et al. 2008). In the short run—that is, within the time it takes new generation to be built or to retire—the shifting of the supply curve reduces market clearing prices, because more-expensive units are no longer needed to meet demand in hours with RE generation. Retail electricity rates are impacted by wholesale power prices insofar as the utility serving electricity consumers purchases power on wholesale spot markets or via contracts with generators that are indexed to wholesale power market prices. Reduced wholesale market prices resulting from increased deployment of RE can thereby potentially reduce retail electricity prices and bills paid by end-use consumers.

The wholesale price effect has been estimated for RE through both model simulations (e.g., Sensfuß et al. 2008; Fagan et al. 2013; GE Energy Consulting 2014) and empirical analysis (e.g., Woo et al. 2011; Woo et al. 2013; Gil and Lin 2013). The effect has also been considered in a wide array of regulatory and policymaking forums, including those that have considered RPS policies (e.g., IPA 2013), transmission expansion (e.g., Fagan et al. 2012), and solar value (e.g., Perez et al. 2012), along with cost effectiveness estimates of demand-side efficiency programs (Hornby et al. 2013). State-level analyses of RPS policies have also sometimes considered this wholesale price effect (Barbose et al. 2015; Heeter et al. 2014).

In this section, we quantify the potential effects of state RPS programs on wholesale electricity prices and estimate the associated bill savings to electricity consumers. It is important to recognize, however, that these cost savings to electricity *consumers* come at the expense of *owners or shareholders* of electricity generating companies, because lower wholesale prices also imply reduced revenues for generators. In other words, any RPS-induced reduction in wholesale prices represents a transfer of wealth from producers to consumers, rather than a net societal benefit (Felder 2011). Keeping with the terminology used throughout this report, we therefore refer to the wholesale price effect as an *impact* rather than a *benefit*.

Methods

Our methods to value the potential wholesale price reduction impacts from state RPS programs in 2013 involve first developing regional supply curves, based on the AVERT outputs, that relate wholesale prices to electricity demand (see Figure 7.1). We then use those supply curves to generate "unadjusted" wholesale prices with and without RPS generation, and finally we quantify the resulting cost reductions seen by end-use customers, based on a set of adjustments that will be described later in this section. These methods are broadly similar to those used in previous analyses of the wholesale price effect of renewables and demand-side measures (see citations above). The unique contribution of our analysis is the use of AVERT to develop supply curves, and the application of a common methodology across all regions of the United States.

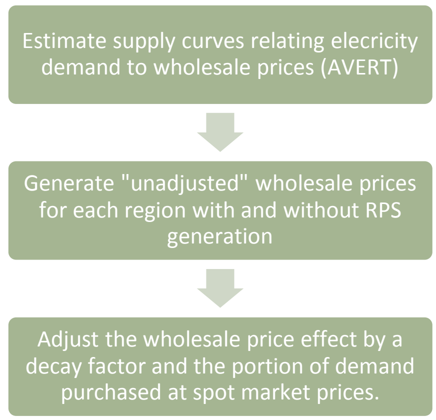


Figure 7.1. Wholesale electricity price impacts methods overview

To develop supply curves for each AVERT region, we calculate the wholesale price in each hour as the change in production cost for that hour's change in total generation, using outputs from the AVERT modeling described in Section 2. Specifically, the change in production cost in each hour is estimated based on the change in fuel consumption, derived from AVERT outputs, and U.S. Energy Information Administration (EIA) data on historical fuel prices for each AVERT region.[51] We then plot the calculated wholesale price and the corresponding demand level for all hours of the year (see the data points labeled "Raw AVERT" in the left-hand panel of Figure 7.2, which illustrates a single AVERT region). The final regional supply curve is estimated by fitting a third-order polynomial with a positive slope to the price/demand pairs (the line labeled "Smoothed" in the left-hand panel of Figure 7.2). We then use that smoothed supply curve to estimate hourly wholesale prices with and without RPS generation in each AVERT region (right-hand panel of Figure 7.2). As expected, lower wholesale prices occur more frequently with RPS generation than without it (as indicated by a narrower probability density curve with a shorter upper tail).

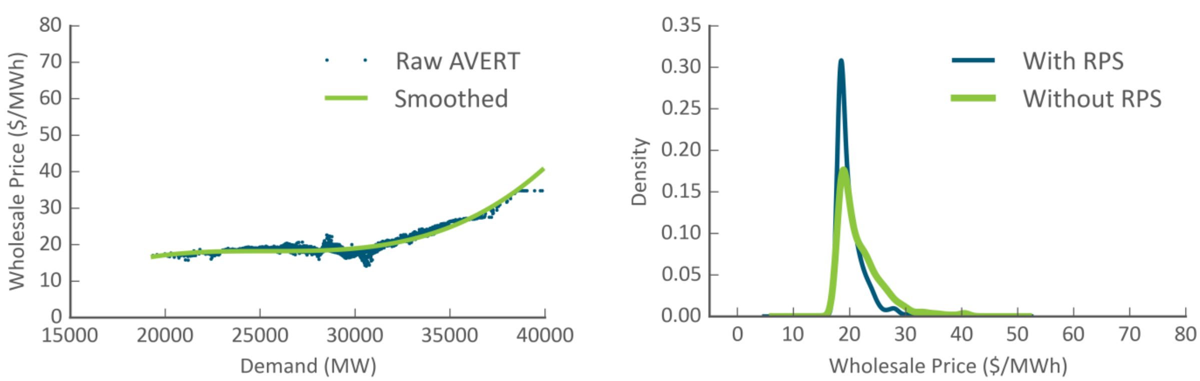


Figure 7.2. Example supply curve

Upper Midwest AVERT region (left) and "unadjusted" wholesale prices with and without RPS generation for the Upper Midwest AVERT region (right)

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[51] The change in production cost is based on AVERT's estimates of the change in fuel consumption at each plant for each hour and quarterly estimates of fuel costs from EIA. Fuel prices from each quarter of 2013 by region were collected from http://www.eia.gov/electricity/data/browser/

Through this process, RPS generation is found to drive down wholesale prices; however, these are "unadjusted" effects that overstate actual wholesale price reductions and consumer savings. To properly estimate both the wholesale price reductions and potential consumer savings, we adjust for two factors: (1) the degree to which the impact of RPS generation on wholesale prices persists into 2013 (i.e., the decay factor), and (2) the extent to which retail electricity consumer bills are exposed to wholesale prices.

The first adjustment is required because the impact of RPS generation on wholesale prices may erode over time. In the short-run, lower wholesale prices lead to reduced revenues for generators, dampening the incentive for new generators to enter the market or for existing generators to remain in operation (Traber and Kemfert 2011; Woo et al. 2012). Over time, the market will re-equilibrate as lower wholesale prices delay the entry of new generators and accelerate the retirement of others, shifting the supply curve back toward its original position. Additionally, in the long run, a number of studies show that, with high levels of variable generation, the overall generation mix will shift away from technologies with high up-front costs and low variable costs (i.e., coal and nuclear plants) and toward technologies with low up-front costs and higher variable costs (i.e., natural gas plants) (Sáenz de Miera et al. 2008; Lamont 2008; Bushnell 2010). The increased investment in plants with higher variable costs further suggests that wholesale market prices may not decline over the long term to the same degree observed in the short term.

We account for this impact through a "decay factor" that reduces the short-run price effect based on the length of time that the market has had to re-adjust to RPS generation. Unfortunately, there is no clear empirical foundation for the duration of this adjustment period. In previous studies, application of a decay factor rests on analyst judgment. We therefore bound our results based on the range of decay factors used in the literature (e.g., Hornby et al. 2011; Hornby et al. 2013) and assume that the wholesale price effect decays linearly over 5, 10, or 20 years, with no effect after the final year.

In addition to the duration of the decay period, a related methodological question is at what point the market adjustment commences. In the absence of any significant literature on this topic, we bound our results by considering two options: either the decay begins at the date of RPS enactment (RPS Vintage) or it begins as new renewable generators are built (RE Project Vintage). The RPS Vintage assumption implies that market participants have the foresight to anticipate when new RPS generation will enter the market as soon as the RPS becomes law, and alter their investment and retirement decisions accordingly. The RE Project Vintage assumption implies that market participants only begin to change investment and retirement decisions once new RPS generation enters the market and can be observed to impact dispatch and power prices. This same methodological issue and source of uncertainty also arises in the analysis of natural gas price impacts, as described in Section 8.

A second adjustment is needed to reflect the fact that not all end-use customer demand is supplied by generation purchased at wholesale spot market prices. Rather, some portion of customer demand is hedged, either through long-term power contracts or utility ownership of generation; only the portion supplied by purchases tied to wholesale prices is impacted by reductions in wholesale prices. To roughly approximate the portion of retail electricity generation costs exposed to wholesale market prices, we use historical EIA data on changes in retail rates and changes in average wholesale prices to estimate the relationship between the two.[52] We find that historical changes in wholesale prices flow through to the energy portion of retail electricity rates at 30%–80% of the wholesale price changes, depending on the region and analysis approach. We assume that regions with organized wholesale power markets[53] tend to feature greater levels of purchases tied to those prices than elsewhere. Based on this analysis and assumptions, we define two cases: a "Low Share" case, where 50% of energy purchases are based on wholesale prices in regions with

[52] Retail price data were collected from http://www.eia.gov/electricity/data/state/avgprice_annual.xls, and wholesale price data were collected from http://www.eia.gov/electricity/wholesale/

[53] The AVERT regions with organized wholesale market exchanges are CA, EMW, NE, SC, TX, and WMW.

organized markets and 30% elsewhere; and a "High Share" case, where 80% of energy purchases are based on the wholesale price in regions with organized markets and 50% elsewhere. Because these are broadly applied estimates, we focus on aggregate national results and do not present results on a regional basis.

Several issues related to the methodology and associated limitations, some discussed earlier, deserve note:

- It is important to reiterate that the electricity consumer benefit calculated here represents a wealth transfer from electricity producers to consumers. No net societal benefit is claimed.
- Though broadly consistent with other studies, assumptions related to the decay factor are uncertain. To reflect and bound this uncertainty, we apply a wide range of assumptions, both for when the decay begins and its duration, yielding a correspondingly wide range of impact estimates.[54]
- Finally, most electricity consumers are not fully exposed to wholesale price. We address uncertainty around the degree of exposure by estimating the impacts under a wide range of assumptions about the share of purchases tied to wholesale electricity market prices.

RESULTS

Based on these methods, we first estimate the magnitude of RPS-induced wholesale price reductions prior to any adjustments for decay or wholesale price hedging in the retail market. Across AVERT regions, the unadjusted wholesale price effect ranges from 0.0 to 0.5¢/kWh-load, or from 0.8 to 4.7¢/kWh-RE. The magnitude of this unadjusted effect is within the range suggested by the broader literature.[55] The variation across regions also aligns with expectations based on market fundamentals. For example, the effects of additional renewable generation on wholesale prices are greater in regions with steeper supply curves, which occur when the wholesale electricity market is supplied by many different types of generators with a variety of fuel types and efficiencies.[56]

More importantly, after adjustments, the magnitude of aggregate, national consumer savings resulting from wholesale price reductions range from an estimated $0 to $1.2 billion (Figure 7.3). To put these figures in another context, as also shown in Figure 7.3, these consumer savings are equivalent to a levelized impact

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[54] The generation-weighted average age of existing RPS policies is nearly 12 years and the generation-weighted average age of new renewable energy delivered for 2013 RPS compliance is just over 4 years. As such, the choice of decay with RPS Vintage or with RE Project Vintage along with the assumption of whether the wholesale price effect decays over 5, 10, or 20 years greatly impact the estimate of the wholesale price effect from 2013 RPS generation.

[55] For example, IPA (2013) estimated a value of 2.1¢/kWh-RE for wind in the Midwest, while our AVERT method estimated 2.5¢/kWh-RE for the WMW and EMW region. More generally, a broad literature review conducted by Würzburg et al. (2013) created a common metric of $/MWh-RE per % of renewables across many studies, primarily from Europe. The median value across studies was $0.73/MWh-RE per % RE. Using this value would lead to estimates of 0-1.0¢/kWh-RE, depending on the region, for the RE penetration levels we are considering. On the other hand, other studies find much larger possible effects. A report on transmission in MISO (Fagan et al. 2012), for example, estimated a price suppression benefit of $7.9 billion for 20 GW of wind or $12.2 billion for 40 GW of wind, implying a wholesale price impact of 9.9-12.9¢/kWh-RE. Moreover, Perez et al. (2012) estimate the wholesale price effect of solar in the mid-Atlantic region to be around 5.5¢/kWh-RE, comparable to the high end of our range.

[56] To understand regional variation in the wholesale price effect, we created a number of supply curves based on data from the Ventyx Velocity Suite for regions that loosely match AVERT regions. These give some indication of the slope of the supply curve in each region, between maximum and minimum load. Based on this assessment, the effect is found to be large in the Northeast due in part to high natural gas prices, particularly in Q1 2013, and the high cost for oil units. The supply curve is much steeper in the Northeast than in other parts of the country, leading to the high wholesale price reduction value. The supply curves in the Southwest, Texas, and Lower Midwest regions, meanwhile, are all relatively flat. In many cases, this is due to a high share of coal or a large number of efficient CCGTs that have production costs similar to coal plants (at 2013 natural gas prices). The Upper Midwest region, on the other hand, has very low coal prices and a large supply of coal generation, but few efficient CCGTs. That means that the supply curve jumps from coal to less efficient CTs or natural gas steam generators relatively quickly, thus leading to a higher effect here than other nearby regions. The California supply curve appears flat due to a large share of natural gas. The Northwest has a substantial portion of coal (with most having a relatively high heat rate of 10 MMBTU/MWh) along with a large number of efficient CCGTs: this generation stack leads to a relatively flat supply curve and a low wholesale price effect. The large amount of hydropower in the Northwest and California may also play a role in flattening the supply curve.

from RPS programs of 0.0 to 1.2¢/kWh-RE. The high level of uncertainty reflected in these ranges is consistent with the broad range of assumptions used for the decay of price effects and the portion of retail electricity sales exposed to wholesale spot market prices.

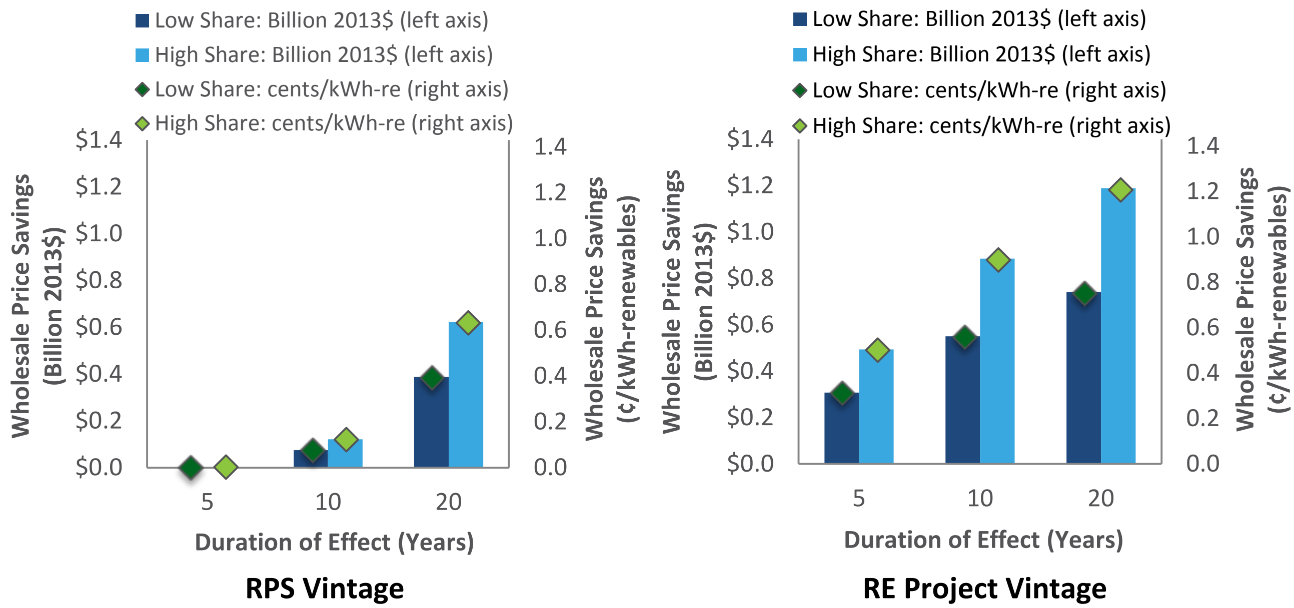

Figure 7.3. Estimated impacts of RPS compliance on consumer savings from wholesale price reductions depending on start of decay

RPS vintage (left) vs. RE project vintage (right), duration of decay, and hedging assumptions

If wholesale price impacts begin to decay at the date of RPS enactment (the left-hand panel of Figure 7.3), the aggregate consumer savings are relatively small, given the age of most RPS policies. At the low end, if the decay occurs over only 5 or 10 years, the wholesale price impact is found to be negligible. If the price effects instead decay over 20 years, the consumer savings are more sizeable, ranging from $0.4 billion to $0.6 billion in 2013, depending on assumptions about the share of customer energy purchased at wholesale power prices.

Assuming, instead, that wholesale price effects begin to decay only once RE projects are built (the right-hand panel of Figure 7.3), the estimated consumer savings are larger, though still uncertain. If the effect lasts for only five years after projects are built, then the wholesale price effect is $0.1 billion to $0.2 billion in 2013. But if the effect lasts for 20 years, the consumer benefits from the wholesale price effect can be as large as $0.7 billion to $1.2 billion in 2013, again depending on assumptions about the share of customer energy purchased at wholesale power rates.

8. Natural Gas Price Reduction Impacts

Renewable generation used to meet 2013 RPS compliance obligations reduced demand for natural gas by an estimated 0.42 quads (422 million MMBtu). This reduction is estimated to have lowered average natural gas prices by $0.05-$0.14/MMBtu in 2013, resulting in consumer savings ranging from $1.3 billion to $3.7 billion. These consumer savings are equivalent to 1.3 to 3.7¢/kWh-RE. The range in estimates reflects two bounding assumptions about when projected natural gas demand reductions begin to affect prices. Importantly, these impacts are best considered wealth transfers from natural gas producers to consumers, rather than net societal benefits.

Introduction

RE generation is frequently noted to impose lower fuel price risk than fossil-fueled generation, due to RE's reliance primarily on inexhaustible fuels that face little or no price uncertainty. Quantifying the benefits of these fuel characteristics has proven to be controversial, however, and a single, standard approach to benefit quantification has not emerged. Methods that have been used to assess these benefits, as well as the benefits of electricity supply diversity more generally, include risk-adjusted discount rates (Awerbuch 1993), Monte Carlo and decision analysis (Wiser and Bolinger 2006), mean variance-based portfolio theory (Awerbuch and Berger 2003; Bazilian and Roques 2008), market-based assessments of the cost of conventional fuel-price hedges (Bolinger et al. 2006), various diversity indices (Stirling 1994; Stirling 2010), comparisons of empirical wind contract prices to gas price forecasts (Bolinger 2013), and estimates of a generation portfolio's sensitivity to high and low fuel prices under high renewable penetration scenarios (Graves and Litvinova 2009; Jenkin et al. 2013).

While standardized tools for quantifying the benefits of energy supply diversity and fuel risk reduction do not yet exist, increased use of RE does mitigate fossil fuel price risks in one way that can be quantified using recognized and—with appropriate caveats—accepted methods. Specifically, in many parts of the United States, natural gas-fired generation is commonly the marginal supply resource within the electricity sector. As RPS-driven renewable generation with low marginal costs comes online, it therefore tends to displace gas-fired generation from the bid stack. This displacement results in a reduction in demand for natural gas among gas-fired generators, which—all else being equal—should place downward pressure on natural gas prices (e.g., Wiser and Bolinger 2007).[57] As a result of these natural gas price effects, previous research has found that, while RPS programs drive up retail electricity prices in certain cases (Barbose et al. 2015), these increases could be partially or entirely offset by suppression of natural gas prices (e.g., Fischer 2009). In this section, we estimate the potential effect of state RPS programs on natural gas prices and related energy bills, recognizing that reductions in natural gas prices benefit *consumers* in all natural gas-consuming sectors of the economy—that is, not just within the electricity sector. These consumer savings, however, come at the expense of natural gas producers.. While individual states may experience net benefits from these transfers—e.g., states that consume more natural gas than they produce—others will experience the opposite. For this reason, we refer to this effect as an *impact* rather than a *benefit*.

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[57] Within a simple economics supply/demand framework, this gas displacement 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 RE generation, per the earlier AVERT results, 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).

Methods

Our methods to value the potential natural gas price reductions from state RPS programs in 2013 are generally consistent with the approaches summarized in Wiser et al. (2005) and Wiser and Bolinger (2007) and recently applied in the DOE's *Wind Vision Report* (DOE 2015). These methods depend on data and assumptions about the amount of natural gas demand reduction, the shape of the natural gas supply curve, and total natural gas demand in the contiguous United States (Figure 8.1). The amount of RPS-induced natural gas demand reduction in 2013 is estimated through the AVERT modeling process described in Section 2, while total natural gas demand comes from the EIA. The shape of the supply curve—measured by its elasticity[58]—is more uncertain.

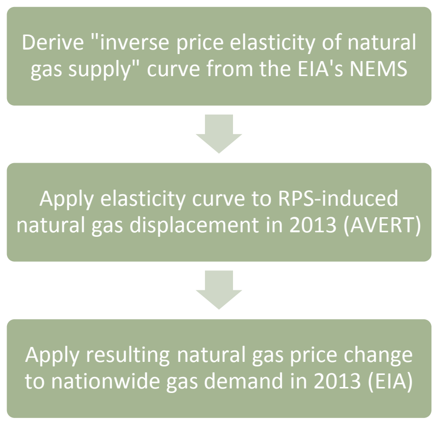

Figure 8.1. Natural gas price impacts methods overview

If the supply curve is steep (or "inelastic"), a demand reduction will cause a larger price reduction than if the supply curve is flatter (or more "elastic"). Because supply is relatively fixed in the near term but has more time to adjust to market conditions over longer periods, supply curves are typically thought to be steeper in the near term than over longer terms. This distinction has important implications for this analysis, given that renewable generation serving RPS requirements in 2013 is attributable to renewable generators that have been built (or, alternatively, to RPS policies that have been enacted) over an extended period, ranging from as far back as the 1990s to as recently as 2013. Presuming that gas supply will eventually adjust to these gas-displacing renewable generators (or RPS policies), the older the renewable generator (or RPS policy), the less of an impact it should have on gas prices in 2013.

For this analysis, we use modeling output from the EIA's National Energy Modeling System (NEMS) to derive an implied *inverse* elasticity curve for natural gas supply. Figure 8.2 shows two curves derived by comparing different EIA-modeled scenarios of natural gas demand,[59] along with the corresponding smoothed curve used for the rest of this analysis. These inverse elasticity curves conform to the

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[58] Elasticity is a measure of how much demand changes in response to a change in price (%ΔQ/%ΔP). For this analysis, however, we are more interested in how prices change in response to a change in demand (%ΔP/%ΔQ), which we refer to as *inverse elasticity*.

[59] The comparisons involve two sets of scenarios from the EIA's *Annual Energy Outlook 2015* (EIA 2015b), to characterize how changes in gas demand impacted modeled prices. Specifically, we compared the *High Economic Growth* scenario (i.e., a high gas demand scenario) to the *Reference* scenario, and also to the *Low Economic Growth* scenario (i.e., a low gas demand scenario). In both comparisons, the inverse price elasticity of supply starts out relatively high at around 4.0 (implying an initial 4% change in price for every 1% change in demand), and declines somewhat smoothly over the next ten years before settling somewhere between 0.5 and 1.0.

expectations laid out above: prices are more responsive in the short term than over the long term. Rather than eventually trending to zero (no price response) over time, however, the inverse elasticity curve eventually settles on a long-term steady-state price impact that is larger than zero, reflecting the fact that natural gas is an exhaustible resource.[60]

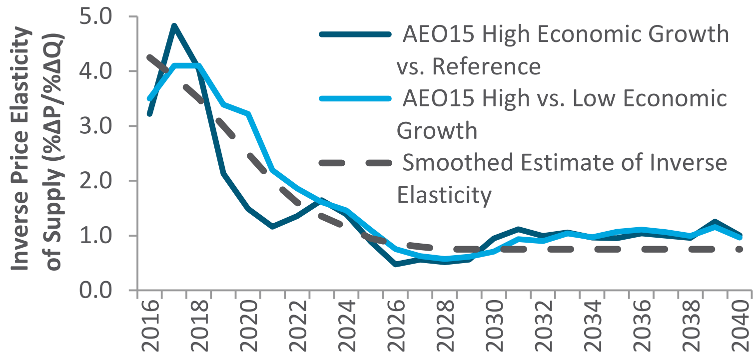

Figure 8.2. Derived inverse price elasticity of supply curve

Next, we apply this derived inverse elasticity curve to the natural gas demand reductions estimated by the AVERT model (and attributed to specific renewable generators and RPS policies, each of which is associated with a particular year) in two different ways, in order to establish a range of potential gas price reductions in 2013. Under one approach, we assume that enactment of an RPS policy was a sufficiently momentous and transparent occasion to cause gas suppliers to anticipate future demand reductions and begin to adjust supply in response. Alternatively, we assume that gas suppliers do not begin to adjust supply until each new renewable generator is built and begins to displace gas-fired generation.

The first approach—measuring the price impact by RPS vintage rather than by renewable project vintage—results in a muted natural gas price response in 2013. This is expected because many RPS policies were enacted in the late 1990s, which places them within the lower, steady-state portion of the inverse elasticity curve (see dark blue bars in Figure 8.3).[61] The second approach—measuring the price impact by renewable project vintage rather than by RPS vintage—results in a larger price response because even those RPS policies enacted long ago have still, in many cases, driven the addition of new renewable generators through 2013, impacting prices through the higher, steeper portion of the inverse elasticity curve (see the light blue bars in Figure 8.3).

[60] This point is perhaps best understood by considering an increase, rather than decrease, in gas consumption: a unit of exhaustible natural gas that is consumed today will not be available for future consumption, and hence drives up the price of all remaining natural gas.

[61] The inverse elasticity curve shown in Figure 8.3 is the mirror image of that shown earlier in Figure 8.2, to reflect that 2013 is the end point rather than the starting point of the analysis period.

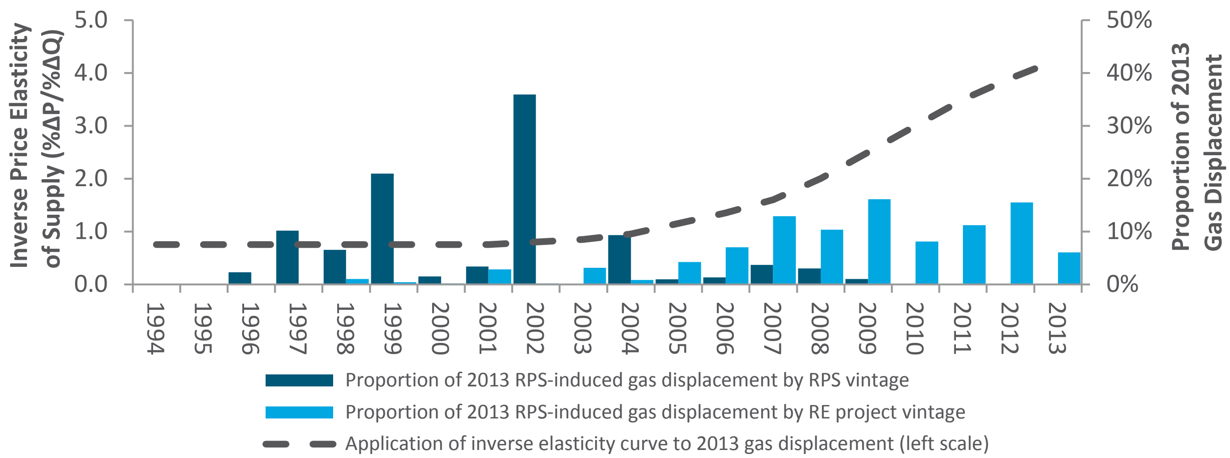

Figure 8.3. Application of inverse elasticity curve to 2013 RPS generation under two bounding scenarios

(by RPS vintage and by project vintage)

The final step in the methodology is to apply the range of natural gas price reductions to nationwide and state-level natural gas demand across all sectors of the economy in 2013.[62] The result provides an indication, in dollars, of the total size of consumer benefits stemming from natural gas price reduction at the sector, state, and national level.

A number of issues related to the methodology and associated limitations, some discussed earlier, deserve note:

- It is important to reiterate that—on a national basis—the consumer benefit calculated here represents a wealth transfer from gas producers to consumers. While individual states, such as those that consume more natural gas than they produce, may experience net benefits from these transfers, others will experience the opposite.
- Though roughly consistent with estimates gleaned from past literature as well as previous approaches to estimating elasticity,[63] the accuracy of the inverse elasticity curve derived for this analysis is uncertain, both in terms of magnitude as well as the timing and rate of decay.
- As described earlier, there is uncertainty over whether the elasticity decay should begin on the date of RPS enactment or once specific renewable generators have been built and have started to displace natural gas. We have bounded this uncertainty by presenting a range of results that are book-ended by these two extreme possibilities.
- The estimated gas price reductions are for average nationwide wellhead prices, and it is unclear to what extent changes in national average wellhead price flow through to delivered gas prices in various states and sectors of the economy. Our analysis assumes 100% pass-through to all states and sectors equally, with no differentiation in elasticities or pass-through by region or sector.
- Related to the previous point, some gas consumers may not be fully exposed to "spot" wellhead price changes, either because they have entered into long-term, fixed-price contracts for gas supply, or because they have implemented some type of price hedge (e.g., through the futures market). Our

[62] Data on natural gas consumption is provided by the Energy Information Administration.
[63] Wiser and Bolinger (2007) reviewed the extant empirical literature for estimates of the elasticity of natural gas supply, but did not find much material and ultimately largely resorted to a similar modeling-based approach as used in this analysis. The model-based elasticity estimates reviewed by Wiser and Bolinger (2007) are consistent with those used here.

analysis assumes that all consumers (in all states and sectors of the economy) are 100% exposed to wellhead price changes.[64]

- Our analysis does not directly account for the possibility of a "rebound effect," whereby RPS-induced gas price reductions spur additional demand, which in turn boosts gas prices somewhat. Although any such rebound effect would result in less of a price reduction than estimated here, the overall dollar impact is less clear, because the smaller price reduction would be applicable to a larger amount of demand.
- Finally, although we present results by state, many commercial and industrial facilities that benefit from lower natural gas prices may be owned by publicly traded corporations whose shareholders reside in different states than those in which the facilities themselves are located.

Results

Based on the AVERT modeling presented earlier, compliance with RPS obligations in 2013 reduced demand for natural gas among gas-fired generators by an estimated 0.42 quads (422 million MMBtu), representing 1.6% of total natural gas consumption in the contiguous United States (and 5% of natural gas consumption within the electricity sector). This reduction in gas demand is, in turn, estimated to have reduced natural gas prices by $0.05 to $0.14/MMBtu, depending on whether the decay of natural gas price effects is tied to RPS vintage or RE project vintage, respectively.

When applied to all gas-consuming sectors of the economy within the contiguous states,[65] the aggregate consumer savings in 2013 range from $1.3 billion to $3.7 billion (Figure 8.4). Primary beneficiaries include gas consumers within the electricity, industrial, and residential sectors, followed by the commercial sector. Importantly, while individual states may experience net gains or losses, these 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 [through rents] and governments and taxpayers [through taxes]) to gas consumers on a national basis.

[64] Given that both gas producers and consumers clearly hedge away gas price risk to some extent, this assumption of "no hedging" is a simplification. That said, long-term, fixed-price contracts are uncommon in the gas industry (Bolinger 2013), and most gas price hedging is instead done on a short-term (e.g., 3 months to several years) basis. As these short-term hedges roll off, they can only be re-implemented at prices that reflect interim movements in the spot market price of gas. In other words, using short-term hedges, one cannot completely insulate oneself over the long-term from spot gas price movements; spot price movements can only be avoided as long as the hedge is in place, and will "catch up" once the hedge rolls off. Given that this analysis focuses on the year 2013, and that the gas price reduction is estimated based either on when RPS policies were enacted or when renewable generators achieved commercial operation – either of which is well in advance of 2013 in most cases (see Figure 8.3) – it is reasonable to assume that any spot gas price reductions resulting from RPS policies have, by 2013, also been largely reflected in the price of short-term hedges. If so, our simplifying assumption of "no hedging" may not distort our results to any great extent.

[65] The application of the price reduction to the contiguous states reflects an implicit assumption that these states comprise a single market for natural gas (as opposed to multiple different regional markets) (see Wiser and Bolinger 2007).

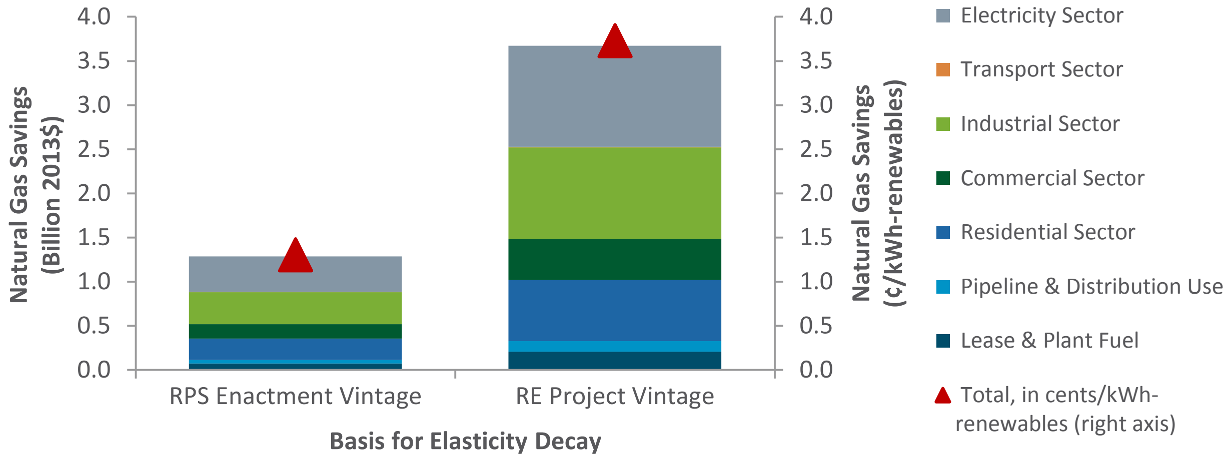

Figure 8.4. Estimated impacts of RPS compliance on natural gas consumer bill savings by sector under two bounding scenarios

To put these figures in another context, as also shown in Figure 8.4, consumer savings from reduced natural gas prices are equivalent to a value of 1.3 to 3.7¢/kWh-RE from new RE used to meet RPS requirements in 2013. These values are broadly consistent with those reported in Wiser et al. (2005) and Wiser and Bolinger (2007).

Figure 8.5 breaks out the consumer gas savings by state.[66] Many of the largest state beneficiaries—e.g., Texas, Louisiana, and Pennsylvania—also happen to be large gas-producing states as well, so those states are also impacted by the offsetting negative effect on natural gas producers.[67]

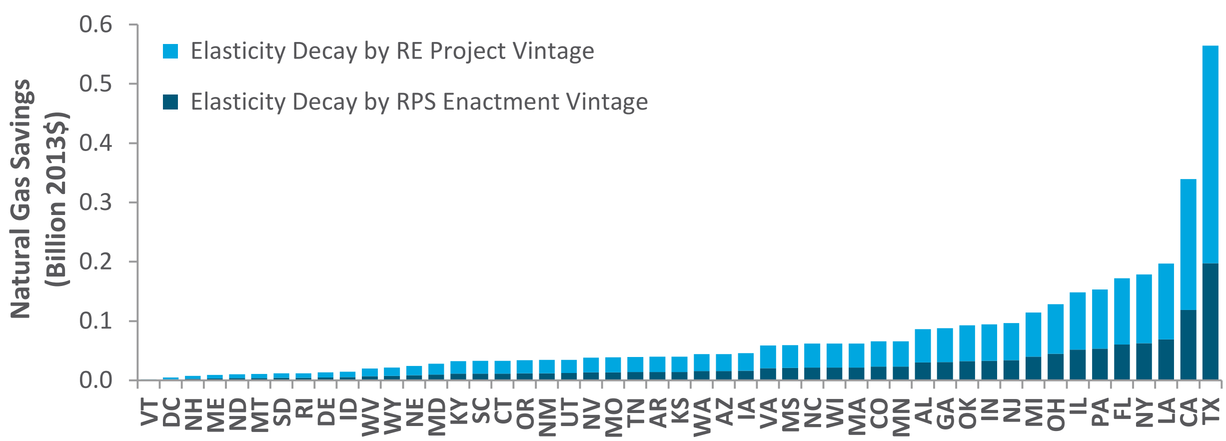

Figure 8.5. Natural gas consumer bill savings by state under two bounding scenarios

[66] Note that these results by state could be misleading, as some of the commercial and industrial facilities that reap gas savings may be publicly traded and widely held by shareholders across the United States.

[67] Though, just as with gas consumers, many gas producers may be publicly traded companies with shareholders located across the United States, in which case attributing lost production revenue to a specific state may also be misleading.

9. Summary and Conclusions

In 2013, RPS compliance obligations were met with 98 TWh of new renewable electricity generation, representing 2.4% of nationwide electricity generation in that year. This renewable generation reduced life cycle GHG emissions by 59 million metric tons of CO_2e; reduced emissions of SO_2, NO_x, and $PM_{2.5}$ by 77,400, 43,900, and 4,800 metric tons, respectively; and reduced water withdrawals and consumption by 830 billion gallons and 27 billion gallons, respectively. Though there is uncertainty in economic value of these effects, using average values, the monetary value of the GHG and air pollution emissions reduction totals approximately $7.4 billion in 2013, or 7.5¢/kWh-RE, under our central estimates. The monetary values of GHG and air pollution emission reductions span $3.3 billion to $16.2 billion, or 3.3¢/kWh-RE to 16.5¢/kWh-RE. Monetary quantification of the reductions in water withdraws and consumption was not estimated due to a lack of available data and consistent methodology for such valuation.

Prior studies summarizing state assessments of RPS costs (Heeter et al. 2014; Barbose et al. 2015) found that annual RPS compliance costs—that is, the incremental cost *net* of avoided conventional generation costs—were generally equivalent to less than 2% of average statewide retail electricity rates over the 2010-2013 period, but varied substantially, with the net cost to utilities and other load-serving entities ranging from -0.4 to 4.8¢ per kilowatt-hour of renewable electricity (kWh-RE).[68] In aggregate, total RPS compliance costs represented approximately $1 billion per year over the 2010 to 2013 period. These costs are borne by utilities and other LSEs subject to state RPS compliance obligations and are generally passed on to retail electricity consumers. Based on analysis in this study, we find that, at a national level, the monetary benefits in 2013 solely from reductions in GHGs, SO_2, NO_x and $PM_{2.5}$ outweigh the approximate annual costs borne to meet state RPS requirements in that single year. Benefits from reduced water use were estimated only in physical, but not monetary, terms for this study, but add further to the societal benefits associated with RPS compliance. This loose comparison notwithstanding, for the reasons discussed in Section 1, additional research would be necessary to formally and accurately compare the costs of RPS policies with the associated benefits and impacts, and considerable uncertainty and nuance underlies any such comparison.

In addition to these health and environmental benefits, RE used to meet 2013 RPS compliance obligations is estimated to have supported nearly 200,000 U.S.-based gross jobs and more than $20 billion in GDP. Average natural gas prices were lowered by $0.05-$0.14/MMBtu, resulting in consumer savings from $1.3 billion to $3.7 billion, or 1.3 to 3.7¢/kWh-RE. The supply curve for wholesale power was potentially shifted, reducing wholesale electricity prices and yielding consumer savings of $0 to $1.2 billion, or 0.0 to 1.2¢/kWh-RE. The analysis of each of these three impacts only quantifies the magnitude of the resource transfer from some stakeholders to others without attempting to determine if there are net societal benefits from these impacts on a state, national, or global scale. However, such impacts might still be considered relevant when evaluating state RPS programs.

Figure 9.1 summarizes the benefits and impacts of new RE used to meet 2013 RPS compliance.

[68] RPS compliance costs represent the incremental cost to the utility or other load-serving entity with RPS obligations, *net* of avoided conventional generation costs. Negative RPS compliance costs may occur when renewable electricity procured to meet RPS obligations is less expensive than avoided conventional generation.

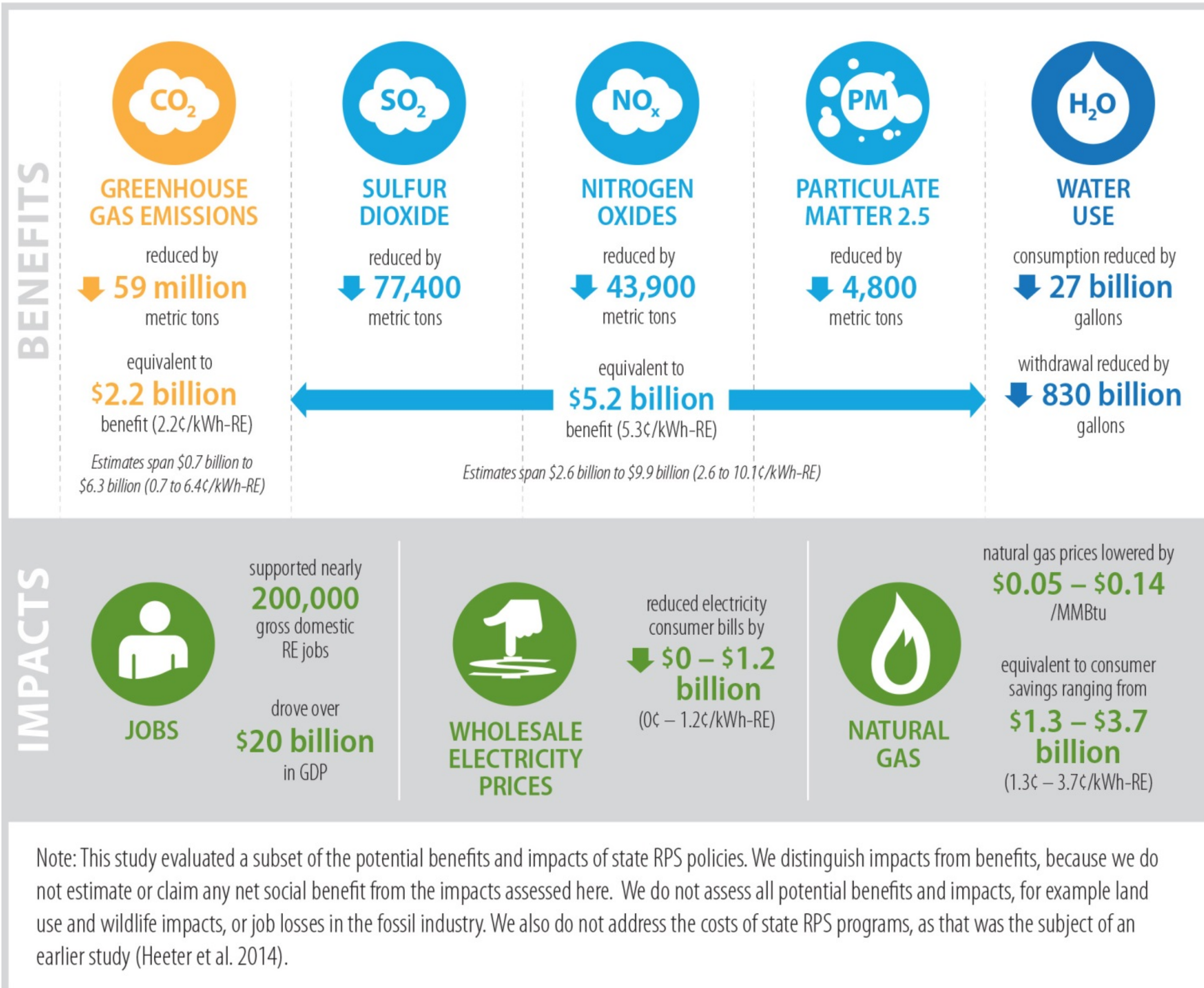

Figure 9.1. Benefits and impacts of new RE used to meet 2013 RPS compliance

These findings may help to inform evaluations of new or existing RPS programs. That said, it is important to acknowledge that multiple drivers exist for RE additions; the benefit and impact estimates presented in this study are therefore not fully attributable to state RPS programs. Moreover, state RPS policies are not necessarily the least-cost approach to achieving the benefits assessed in this report.

Although this study does not evaluate individual state RPS programs, the standardized methods applied in this study may serve as a model for states seeking to evaluate the benefits and impacts of their policies. Individual states, however, may have access to better data or the ability to leverage more specialized tools that provide more-detailed assessments of the benefits and impacts of their particular RPS policies. Depending on the particular benefit or impact, access to more state-specific data or more specialized tools may help to reduce some of the uncertainty surrounding the results presented in this report; for example, more advanced modeling tools could be used to more precisely estimate wholesale market price suppression impacts. Finally, state-level tools and methods may enable an assessment of a broader set of benefits, costs, and impacts than covered in the present paper.

In order to properly compare benefits with costs, additional work is needed to understand the cost implications of RPS compliance. Past state-level assessments, using diverse methods, have shown that RPS compliance costs constituted less than 2% of average retail rates in most U.S. states over the 2010–2013 period, albeit with a sizable range over time and across states, and with data unavailable for a number of key states (Heeter et al. 2014; Barbose et al. 2015). Future work is also needed to understand future benefits, impacts, and costs of RPS polices—as currently enacted and as plausibly expanded. Such prospective analysis could leverage many of the same analytical tools and methods employed in the present study.

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TP-6A20-65005 • January 2016
Printed on paper that contains recycled content.