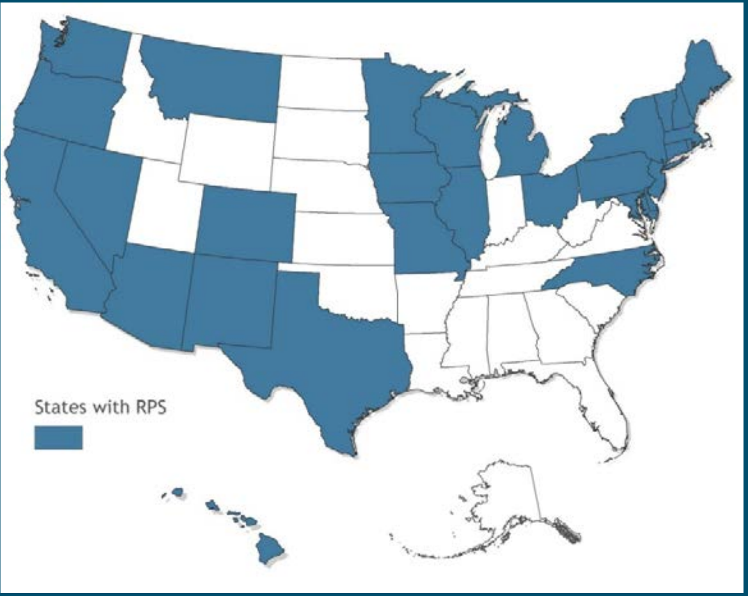
A Retrospective Analysis of the Benefits and Impacts of U.S. Renewable Portfolio Standards

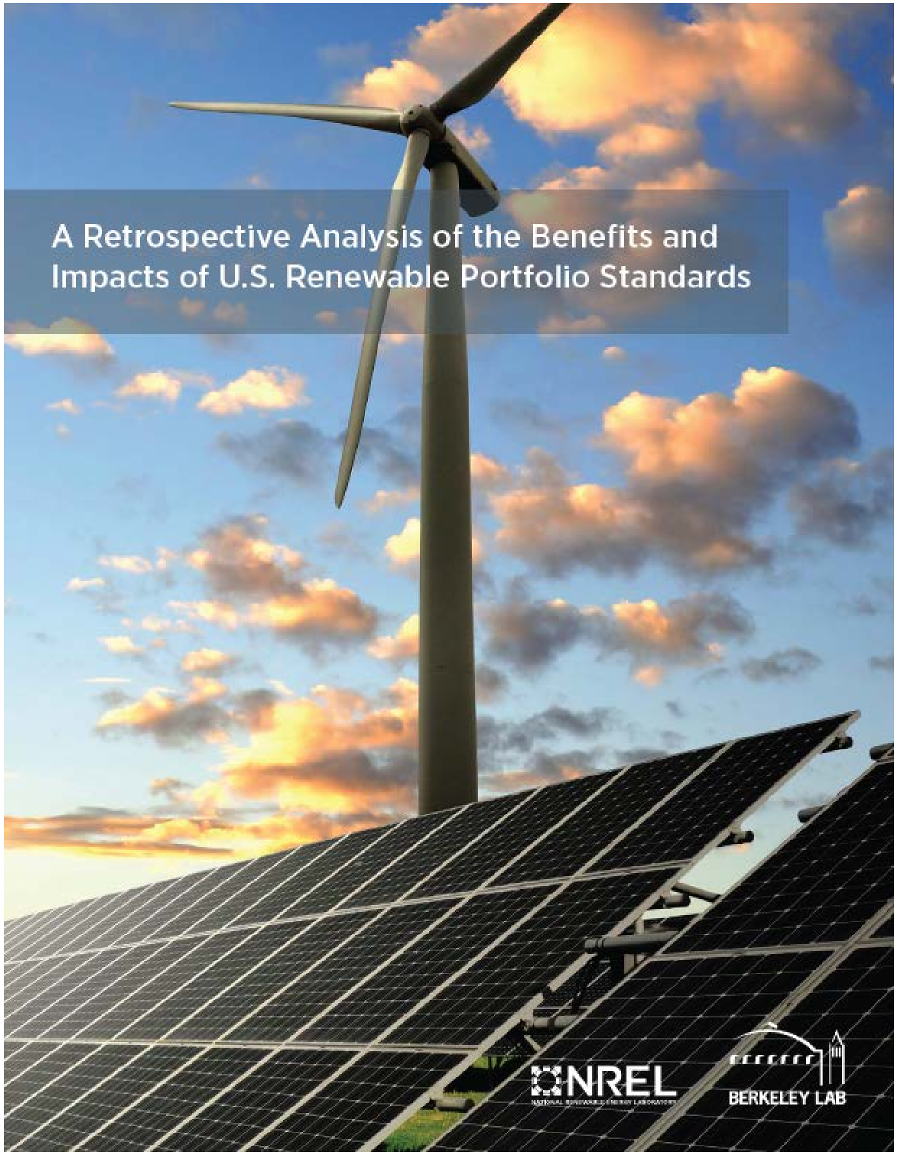


Summary Briefing of Report

January 2016

Presentation Overview

- Overview, background, scope
- Foundational data and analysis
- Greenhouse gas emissions
- Air pollution emissions
- Water use
- Gross jobs & econ. development
- Wholesale electricity prices
- Natural gas prices
- Conclusions

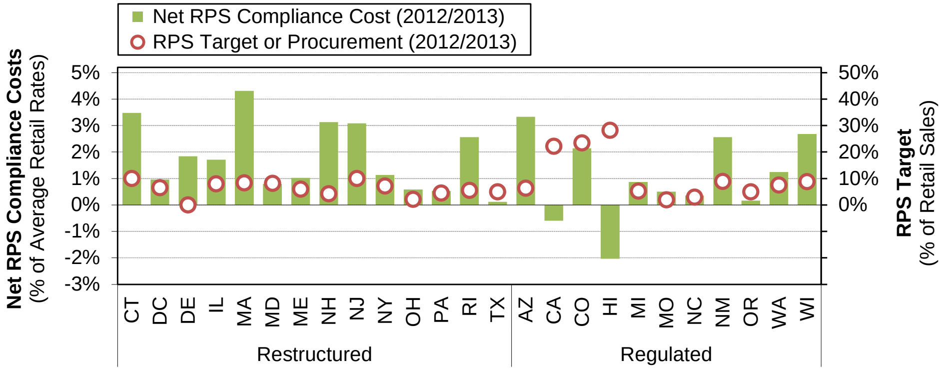


Project Goal, Coverage, Audience

- **Goal:** Evaluate the potential benefits & impacts of state RPS policies to-date, monetized where possible, based on a consistent analytical framework and set of tools *(focused on annual benefits in 2013)*
  - Follow-up to May 2014 NREL/LBNL study on RPS costs (and benefits)
  - Leverage methods used in the DOE Wind Vision study, and elsewhere
  - Taking care to describe full set of caveats, limitations, and uncertainties
- **Coverage:** greenhouse gases, air pollution, water use, gross jobs & economic development, wholesale electricity and natural gas prices
- **Intended Audiences:**
  - **State RPS administrators**: Provide a framework and methodology that states can build upon and refine for their own analyses; methods, assumptions, and caveats are all fully documented
  - **Broader audiences**: Communicate aspects of the value of state RPS programs and the scale of various potential benefits/impacts, to inform decision making

Project Background and Team

- **Supported by the DOE EERE Strategic Programs Office**
- **Executed by a respected LBNL/NREL analysis team**
  - Wiser, Barbose, Heeter, Mai, Bird, Bolinger, Carpenter, Heath, Keyser, Macknick, Mills, Millstein
- **Part of multi-year effort to assess benefits, costs, impacts of state RPS policies, retrospectively and prospectively**
  - 2014: report primarily summarizing state-level estimates of RPS compliance costs, retrospectively

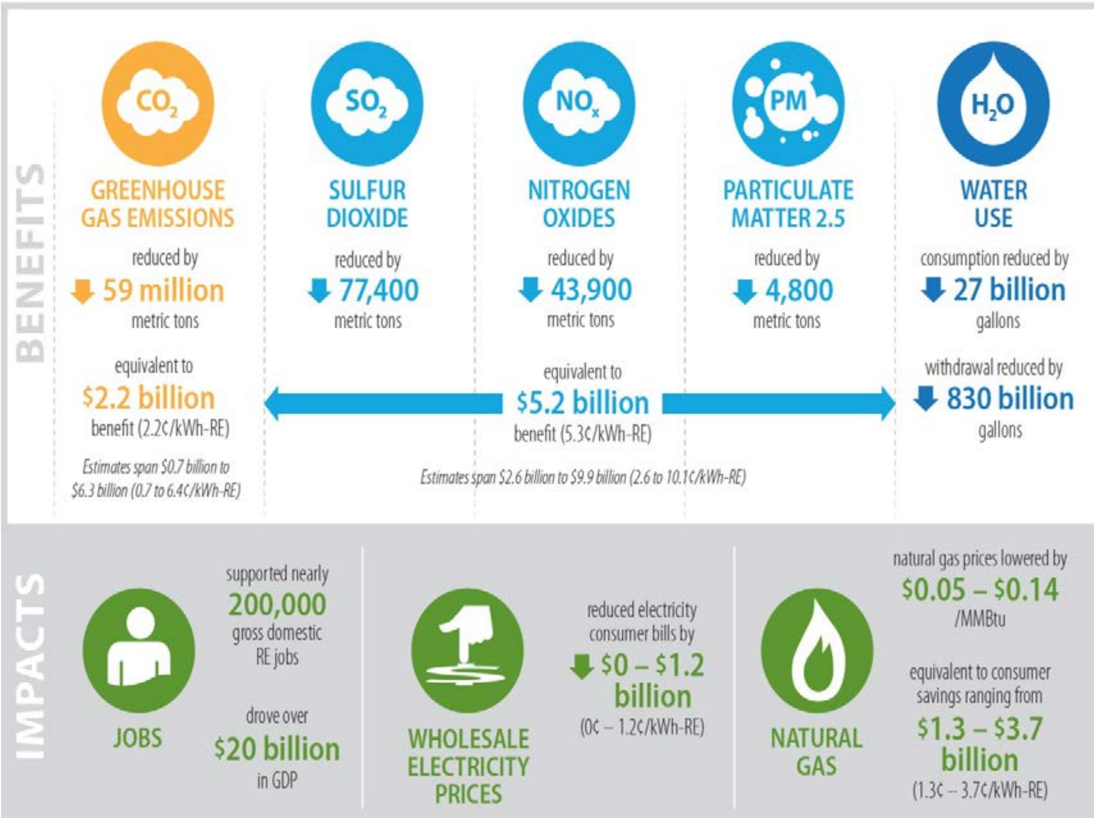


  - 2015: retrospective potential benefits and impacts → ***report focus***
  - 2016: prospective potential costs, benefits, and impacts
  - 2017: TBD, possibly retrospective costs

Study Scope: Limitations and Caveats

Applying Uniform Methods Nationally	• focus on collective potential benefits/impacts of RPS' at national, regional, state levels; do not present impacts of individual states; states might use methods that provide more detailed picture of state-specific results
Uncertainty in Assessment	• we quantify some of the uncertainties in the results, but in other cases we simply highlight and discuss the uncertainties qualitatively
Distinguishing Benefits from Impacts	• benefits (GHG, air pollution, water) vs. impacts (largely resource transfers at national level; gross jobs, wholesale electricity & nat. gas prices)
Coverage of Benefits and Impacts	• analysis considers important subset of issues; aspects unaddressed include land use, array of other environmental impacts, grid integration, etc.
Considering Costs in the Equation	• analysis does not rigorously compare the potential benefits and impacts of RPS' to their costs—a critical comparison for decision-makers
Evaluating Least-Cost Benefits and Impacts	• RPS programs not necessarily the least-cost way of achieving the potential benefits and impacts
Estimating Additionality	• focused on potential benefits/impacts of new RE meeting RPS in 2013; multiple drivers of RE—our analysis does not attribute solely to RPS

Summary of Results: "New" RE Used for RPS Compliance in 2013 Yielded…



Note: This study evaluated a subset of the potential benefits and impacts of state RPS policies. We distinguish impacts from benefits, because we do not estimate or claim any net social benefit from the impacts assessed here. We do not assess all potential benefits and impacts, for example land use and wildlife impacts, or job losses in the fossil industry. We also do not address the costs of state RPS programs, as that was the subject of an earlier study (Heeter et al. 2014).

See following slides for the many caveats and uncertainties that apply to these results

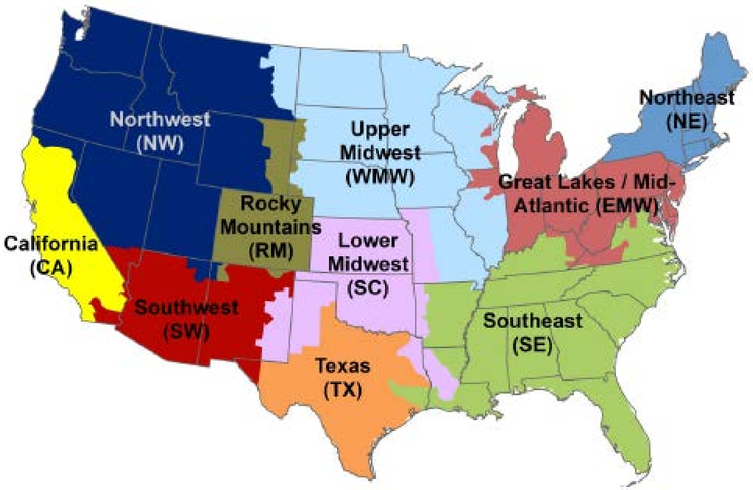
- Sizable uncertainty, but benefits of GHG and air pollution emissions reduction total ~$7.4 billion in 2013, or 7.5¢/kWh-RE, using central estimates
- Previously-estimated average aggregate compliance cost of state RPS programs from 2010-2013 = ~$1 billion/year (Heeter et al. 2014)
  - More work needed for rigorous comparison

Foundational Data and Analysis: RPS Resources and Displaced Fossil Generation

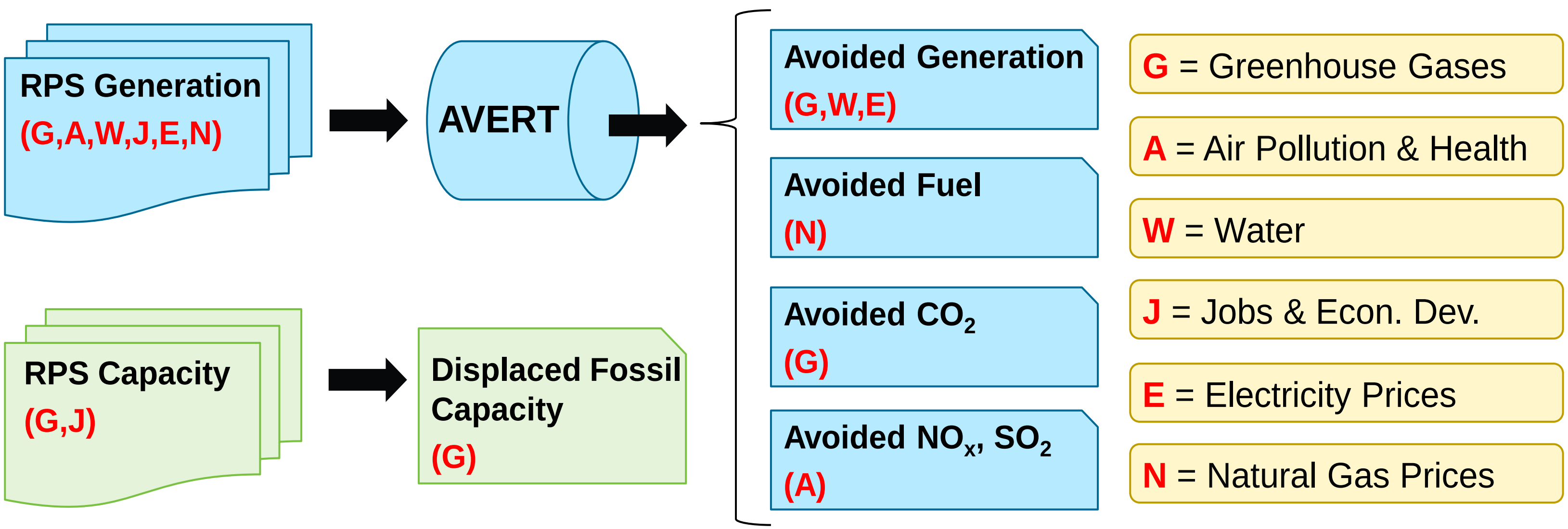
Galen Barbose

RPS Data and AVERT Outputs

- Study utilizes EPA AVERT model to estimate the impact of RPS resources on operation of the existing fossil generation fleet in 2013
- Inputs: Hourly RE MWh delivered to each AVERT region for 2013 RPS compliance
- Output: Plant-level changes in MWh, fuel, and emissions (NOx, SO_2, CO_2) by fossil unit



- The RPS inputs and AVERT outputs both feed into the various benefit/impact analyses (indicated by red letters in schematic)

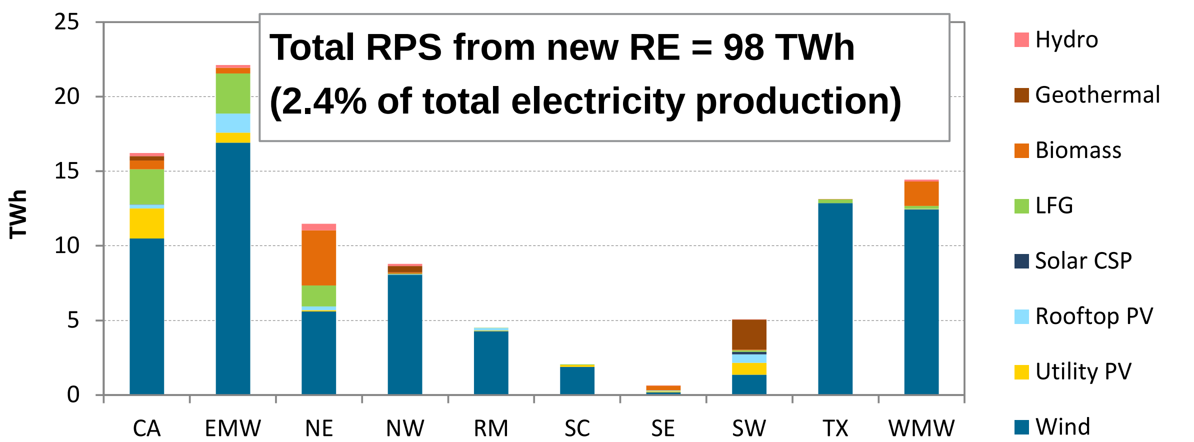


AVERT Inputs: RE Generation for 2013 RPS Compliance

Compiled data on RE used to meet 2013 RPS, drawing from compliance filings and other sources; key conventions (which tend to constrain estimated benefits/impacts):

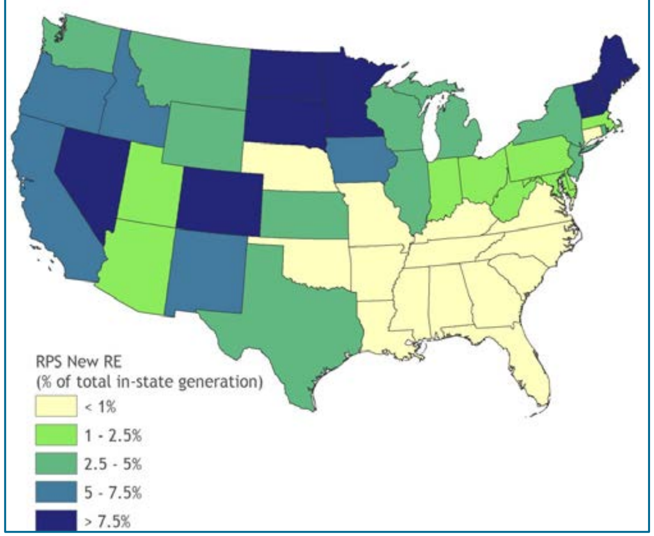
- **New RE only:** Only count generation from RE capacity constructed after RPS enactment
- **Exclude excess RPS procurement:** Only count RE up to amount required by RPS in 2013
- **Exclude non-RE resources:** Only include RE resources in analysis (not EE, CHP, etc.)
- **Exclude Hawaii:** AVERT only covers continental U.S.
- **Inter-regional trade**: For AVERT, assign RPS generation to region where the *electricity* is delivered (which may differ from where RECs are used)

New RE Delivered to Each AVERT Region for 2013 RPS



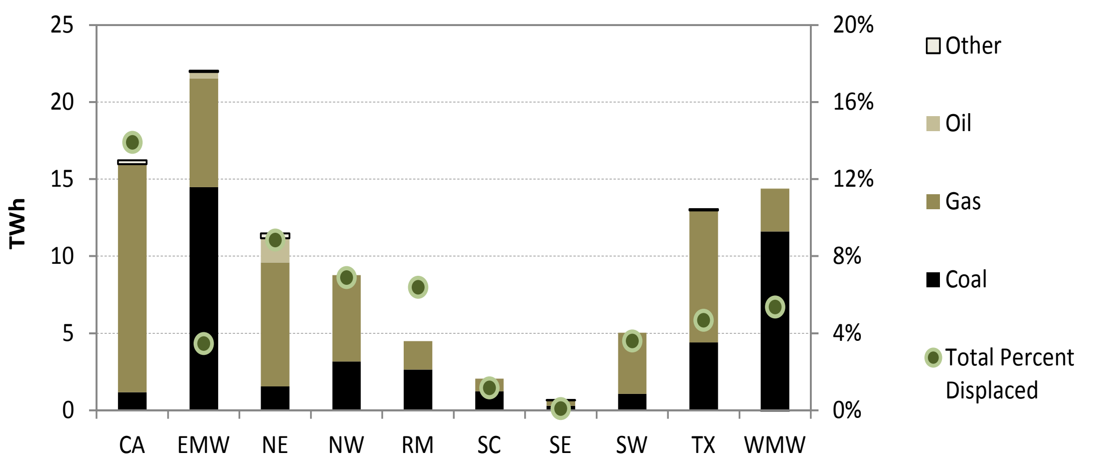
CA=California, **EMW**=Great Lakes/Mid-Atlantic, **NE**=Northeast, **NW**=Northwest, **RM**=Rocky Mountains, **SC**=Lower Midwest, **SE**=Southeast, **SW**=Southwest, **TX**=Texas, **WMW**=Upper Midwest

New RE by State for 2013 RPS



AVERT Outputs: Displaced Fossil Generation, Fuel, Emissions in 2013

Displaced Fossil Generation by AVERT Region



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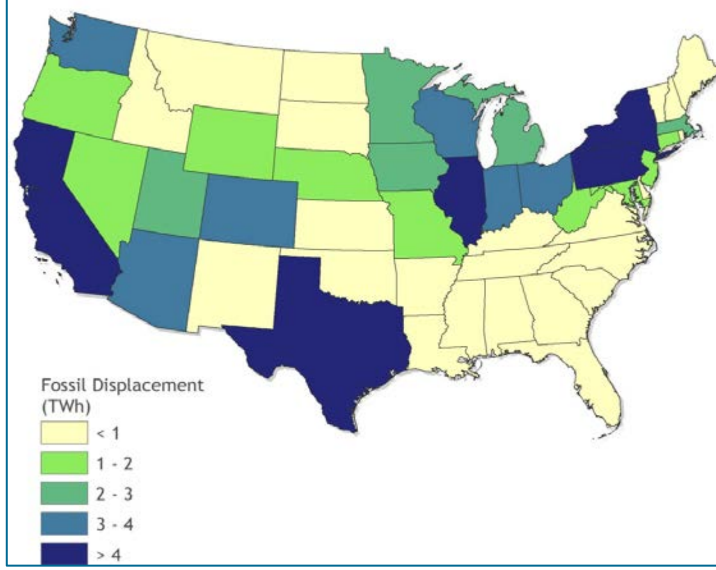
Displaced Fossil Gen. by State



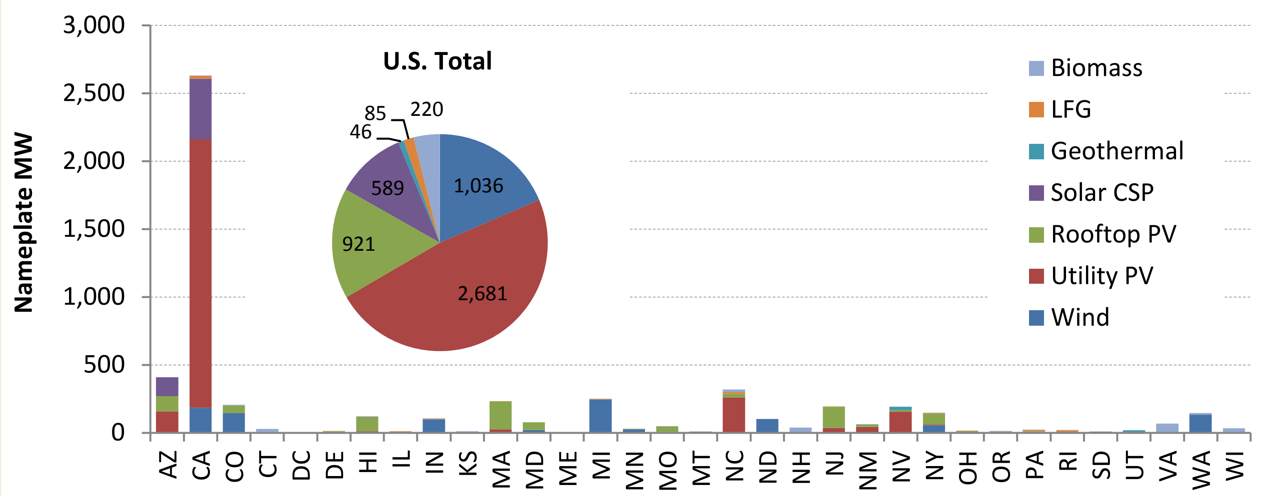
Impacts: New RE used to meet RPS reduced fossil generation by 3.6%, 55% of which was natural gas and most of the rest was coal

Possible limitations to use of AVERT: (1) intermediate approach in terms of complexity and accuracy; (2) insensitive to location within AVERT regions and does not fully consider cross-region interactions; (3) limited ability to accurately model large RE programs

RPS Capacity Additions and Displaced Fossil Capacity: Needed for LCA GHG and Jobs

RPS Capacity Additions

- Average of 2013-14 additions (construction often begins year before online date)
- Count if PPA/REC off-taker has RPS or if merchant plant sold into RTO with RPS
- Exclude RE capacity in excess of final-year RPS targets (TX and IA)



Average annual additions equal ~5,600 MW

Displaced Fossil Capacity

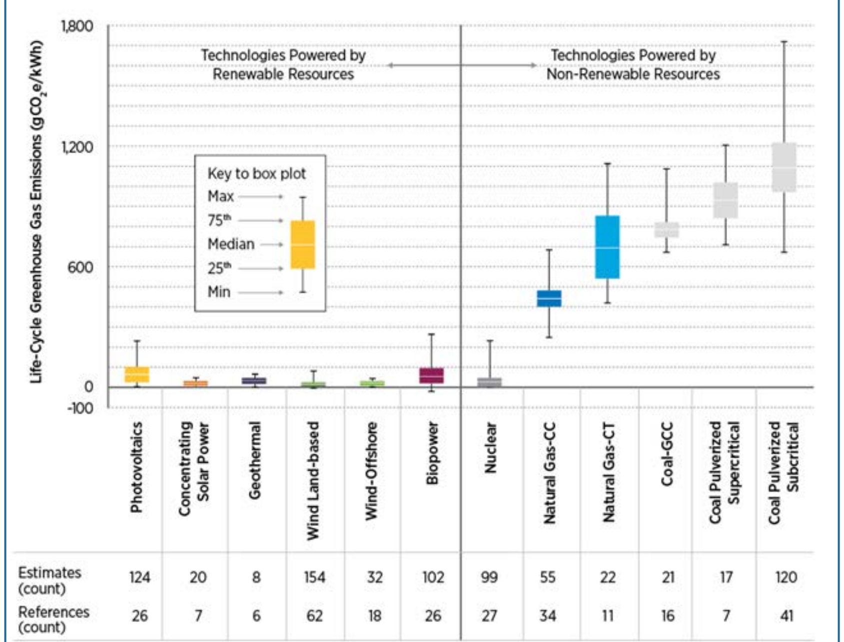
- Simple estimate based on assumptions for capacity credit and mix of displaced fossil capacity (both varying by RE fuel type)
- **Result = >2,500 MW displaced fossil capacity** (1,600 MW CCGT + 960 MW CT)

Greenhouse Gas Emissions and Climate Change Damage Reduction Benefits

Garvin Heath, Alberta Carpenter, Ryan Wiser

- Scientists predict significant changes to the climate due to GHGs, threatening human health and well-being; putting infrastructure at risk; jeopardizing water quality and supply; disrupting agricultural production; and negatively affecting ecosystems and biodiversity
- RE technologies have low GHG emissions when considering all life cycle stages from upstream materials requirements to operations and decommissioning
- We estimate the potential life cycle GHG benefits of RPS compliance, quantifying the value of those reductions in mitigating the severity of climate-related damages

Life Cycle GHG Emissions from Electricity Generation Technologies



Note: Acronyms used in this figure: Natural Gas-CC = Natural gas combined cycle; Natural Gas-CT = Natural gas combustion turbine; Coal - IGCC = Coal integrated gasification combined cycle

Methods and Caveats

Estimate combustion-related CO_2 emissions reductions (AVERT)

Estimate upstream GHG emissions impacts from other life cycle stages

Value reductions based on range of social cost of carbon (SCC) estimates

SCC reflects impacts on agricultural productivity, human health, property damages, ecosystem services

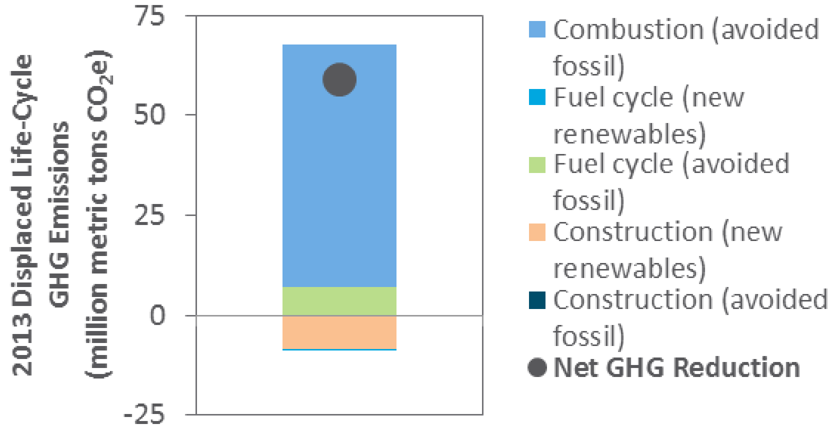
- Rely on four global SCC estimates from the U.S. IWG (central=\$37/metric ton (MT) of CO_2; low =\$12/MT; high=\$59/MT, higher-than-expected =\$106/MT) and apply to life cycle CO_2e; SCC regularly used in federal rulemakings: results reflect future global benefits
- Do not fully consider erosion of GHG benefits due to increased cycling, ramping, and part loading required of fossil generators
- Construction-related life cycle emissions based on average RE capacity additions from 2013-2014, and assumptions for displaced capacity described earlier
- Indirect land-use emissions from biomass not considered given state of literature; assume that landfill gas used for electric production would otherwise have been flared
- Methodology presumes that carbon cap-and-trade programs were non-binding in 2013

Summary of Key Results: Physical Impacts

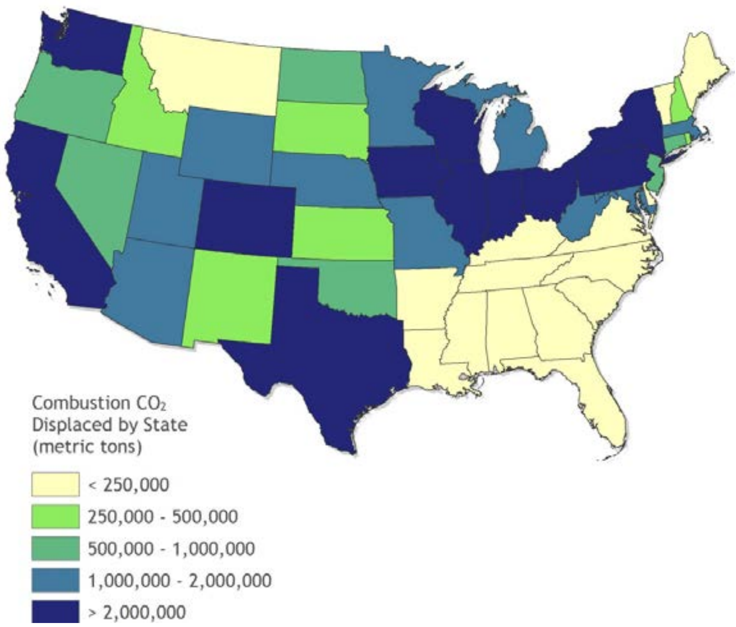
Net displaced CO_2e emissions in 2013: 59 million metric tons

- *Displaced combustion at fossil fuel plants: 61 million metric tons (3% power sector emissions)*
- *Displaced life cycle-related emissions (net of construction and fuel cycle): -2 million metric tons*

Life Cycle GHG Emissions Impacts



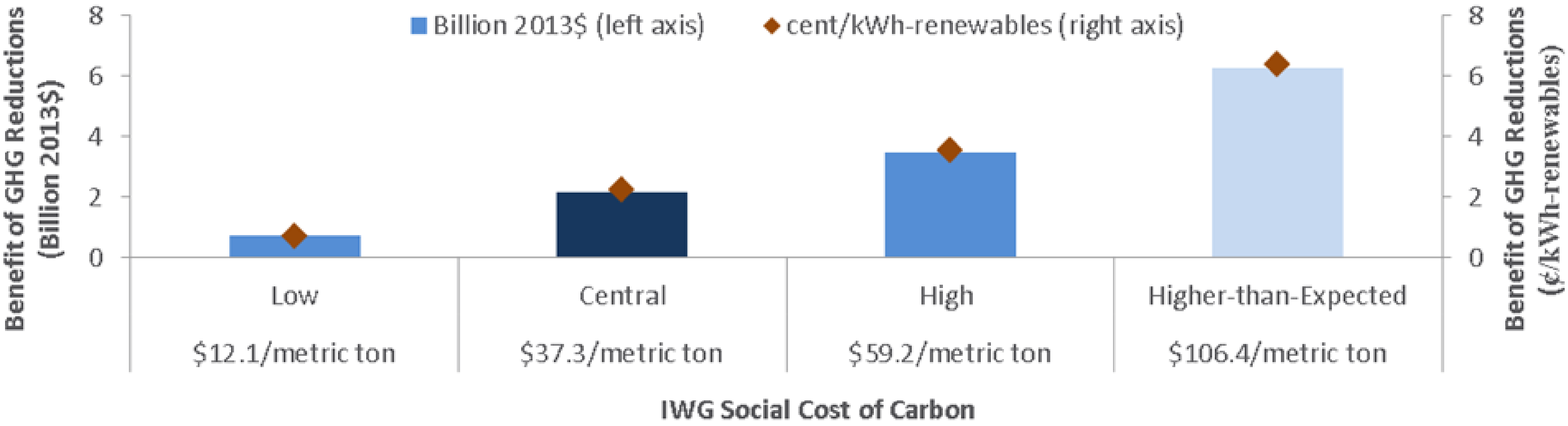
Combustion-Related CO_2 Emissions Reductions



Combustion-related emissions reductions are somewhat concentrated in portions of the Great Lakes, Mid-Atlantic, TX, CA, CO, WA

Summary of Key Results: Monetary Benefits

RPS provided between $0.7 and $6.3 billion in reduced global climate change damages in 2013: **central estimate = $2.2 billion**



GHG benefits are equivalent to:

- Central estimate = 2.2¢/kWh-renewable
- Full range: 0.7-6.4¢/kWh-renewable

Air Pollution Emissions and Human Health and Environmental Benefits

Dev Millstein, Ryan Wiser

Background

- Combusting fuels to generate electricity produces air pollutants that harm human health and cause environmental damage
  - 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
  - EPA (2015) has estimated that the CPP would provide $14 billion to $34 billion of monetized health benefits in 2030
- All energy sources have environmental impacts, but most RE sources have no direct and low life cycle air pollution emissions
- We calculate the potential air emissions reductions associated with state RPS compliance in 2013, and present the associated public health and environmental benefits from those reductions

Methods and Caveats

Estimate combustion-related SO_2, NO_x, and $PM_{2.5}$ emissions reductions (AVERT)

↓

Estimate emissions from 2013 RPS biomass electricity production

↓

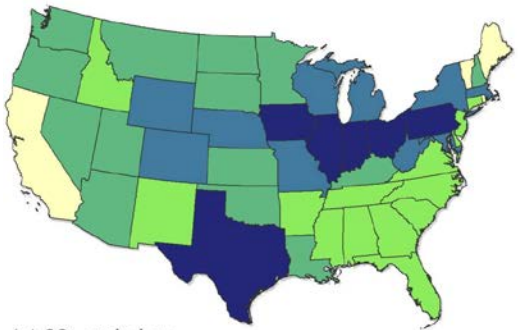
Calculate impacts & monetized benefits of net emission reductions with multiple methods (EPA COBRA and CPP, AP2)

EPA COBRA & CPP (low/high) and AP2 account for pollutant transport and chemical transformation as well as exposure & response, but each does so differently and considers different impacts (see report)

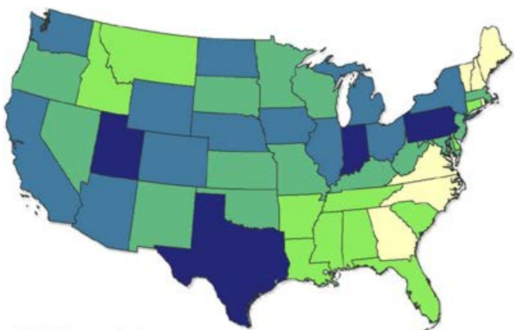
- Focus on subset of air emissions impacts: SO_2, NO_x, and $PM_{2.5}$ emissions, and implications for fine particulate and ozone exposure; only consider plant operations, ignoring life cycle
- Methodology presumes that SO_2 and NO_x cap-and-trade programs, such as the Clean Air Interstate Rule, were not binding in 2013: otherwise, benefits of RPS compliance should arguably be valued at allowance prices
- Uncertainties in $PM_{2.5}$ and biomass emissions are more substantial than fossil-based SO_2 & NO_X
- Do not fully consider erosion of air emissions benefits due to increased cycling, ramping, and part loading required of fossil generators
- Landfill gas assumed to have otherwise been flared, with similar emissions profile

Summary of Key Results: Physical Impacts

Displaced SO_2, NO_x and $PM_{2.5}$ emissions of 77,400 (2% of power sector), 43,900 (2%), and 4,800 (2%) metric tons, respectively

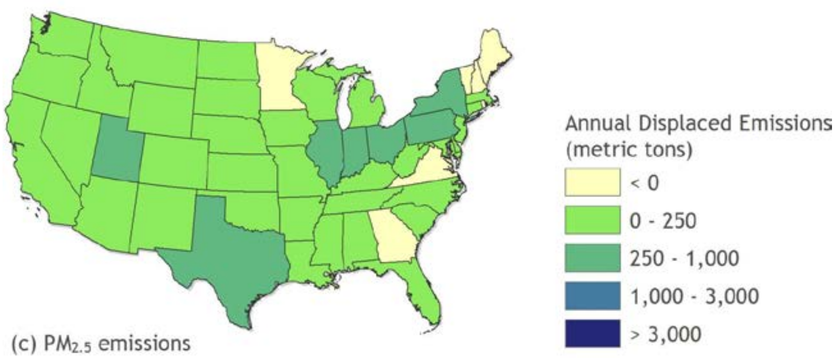


(a) SO_2 emissions



(b) NO_x emissions

Emissions reductions are concentrated in Midwest, Mid-Atlantic, Great Lakes, and Texas

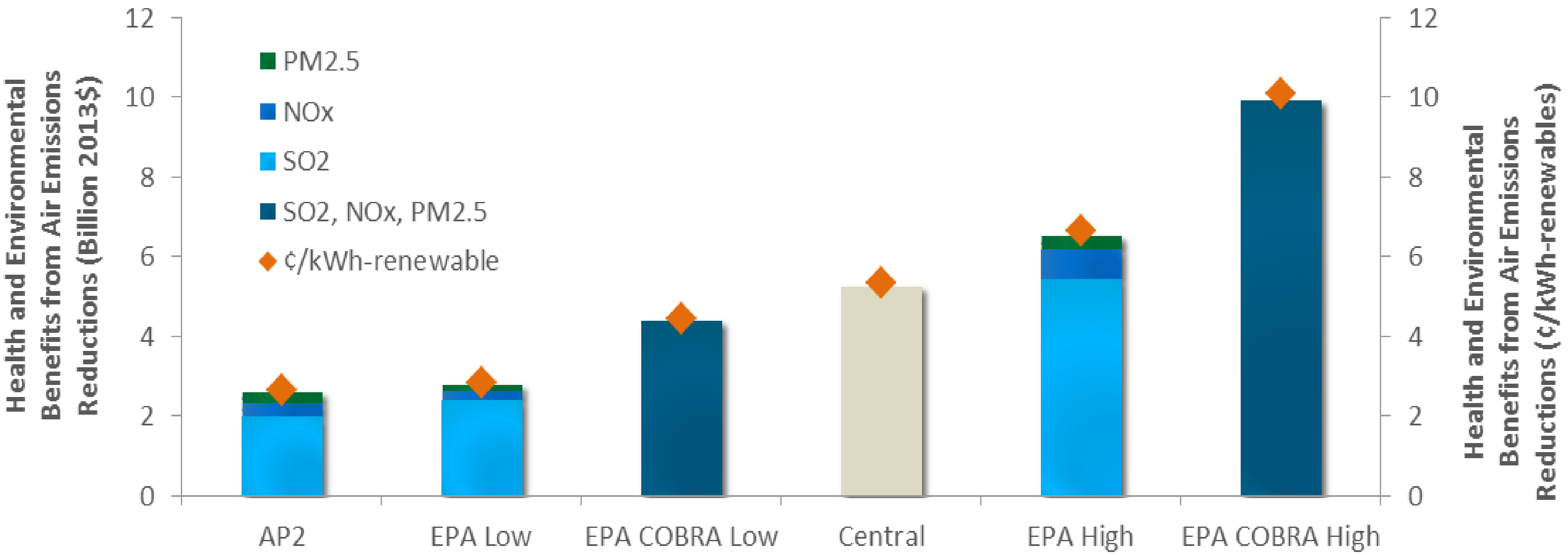


(c) $PM_{2.5}$ emissions

Note: A few states with biomass plants serving RPS compliance are estimated to have had small (relative to emission reductions in other states) emission increases

Summary of Key Results: Monetary Benefits

RPS provided between $2.6 and $9.9 billion in health & environ. benefits in 2013: **central (average) estimate = $5.2 billion**



Air emissions reduction benefits are equivalent to:

- Central estimate = 5.3¢/kWh-renewable
- Full range: 2.6-10.1¢/kWh-renewable

Summary of Key Results: Details on Benefits

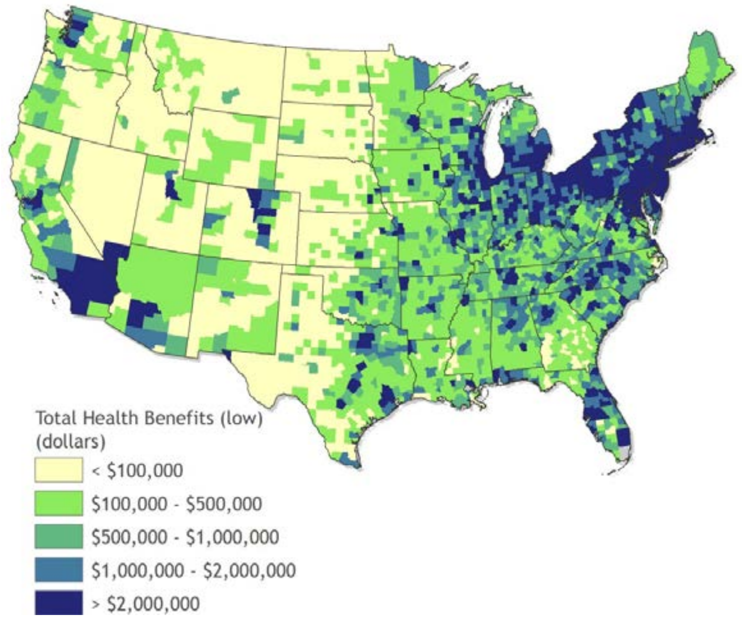
Reduction of SO_2 (primarily from coal) and the subsequent reduction of particulate sulfate concentrations accounted for 77-86% of the monetized benefits; ozone reductions represent 4-7%

Most of the health benefits come from avoided premature mortality, primarily from reduced exposure to $PM_{2.5}$ (largely from SO_2 emissions)

New RE meeting RPS programs in 2013 prevented 320–1,100 deaths, and generated a range of benefits in the form of reduced morbidity

Wide variations in scale of RPS benefits by region: largest benefits accrue to eastern half of country, and especially in Mid-Atlantic, Great Lakes, Northeast, and Texas

Graphic shows regional benefits of RPS in 2013 due to reduced health and environmental damages from particulate matter under the 'COBRA Low' estimates



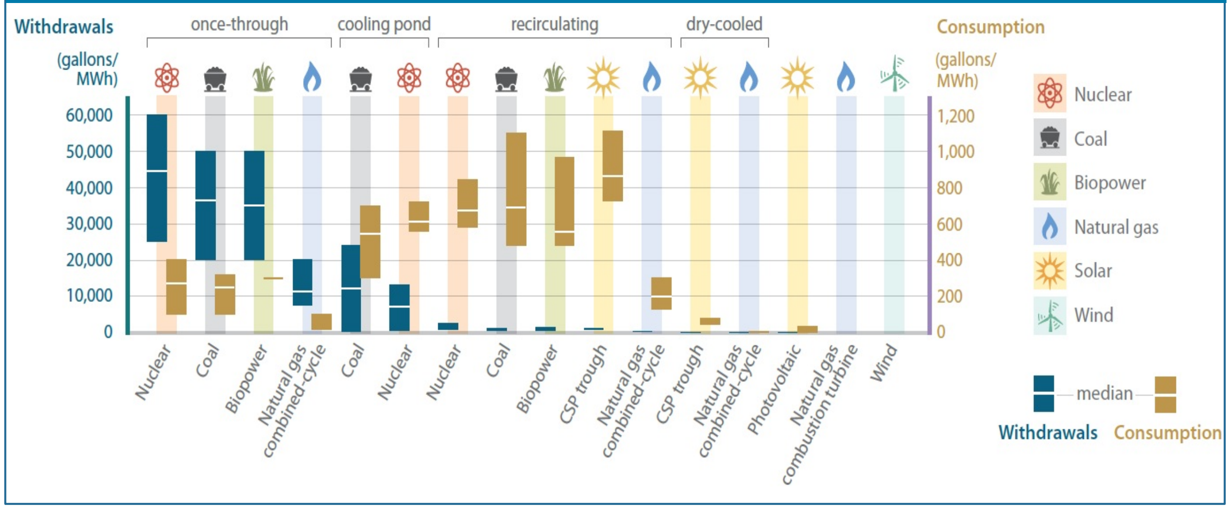
Water Use Reduction Benefits

Jordan Macknick

Background

- Electric sector is heavily dependent on water—primarily for thermal cooling—and can affect water resources through withdrawals, consumption, changes in quality, and changes in temperature
  - Withdrawals: amount of water removed or diverted from a water source (U.S. power sector is largest source of withdrawal , at 38%)
  - Consumption: amount of water evaporated or otherwise removed from the immediate water environment (U.S. power sector = just 3%)
- Many RE technologies have low water use compared to fossil and nuclear technologies
- We calculate potential water withdrawal and consumption benefits of RPS compliance

Operational Water Use of Electric Generation Technologies



Methods and Caveats

Estimate renewable and fossil changes in generation from RPS Compliance (AVERT)

↓

Match power plants in AVERT with database of power-plant water use intensity estimates

↓

Quantify national, regional, and temporal net water use reductions

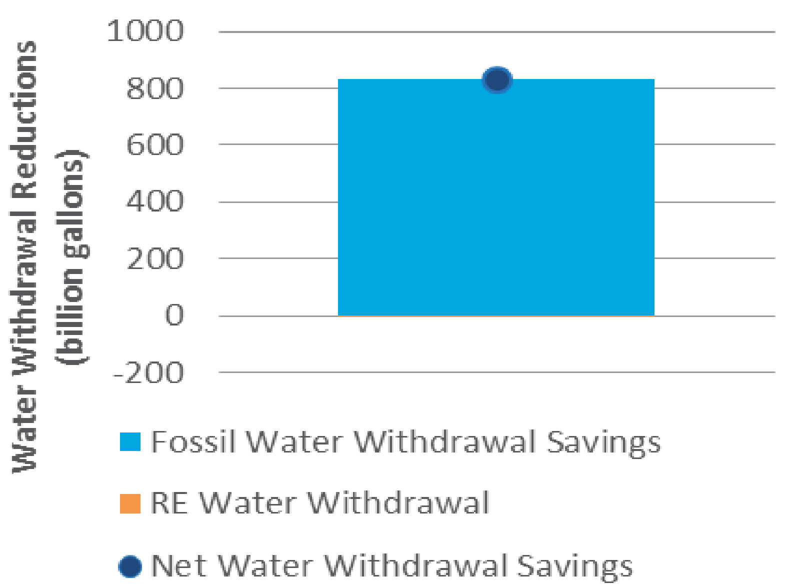
Considers operational water withdrawal and consumption of all fossil, nuclear, and renewable energy sources

- Do not quantify benefits of water use reductions in monetary terms: methodological challenges
- Only consider operational water use and do not estimate full life cycle uses; including upstream uses would likely increase RPS benefits
- Assessment relies on assumptions about which prime mover technology type and cooling system is associated with individual generators
- Biomass (non-gas) sources are assigned water use characteristics of simple-cycle steam turbine solid-biomass power plants, biomass (gas) sources are assigned characteristics of biogas-based power plants, and landfill gas plants are assumed to require no water for operations
- Do not consider hydropower evaporation due to uncertainties in allocation among multiple uses

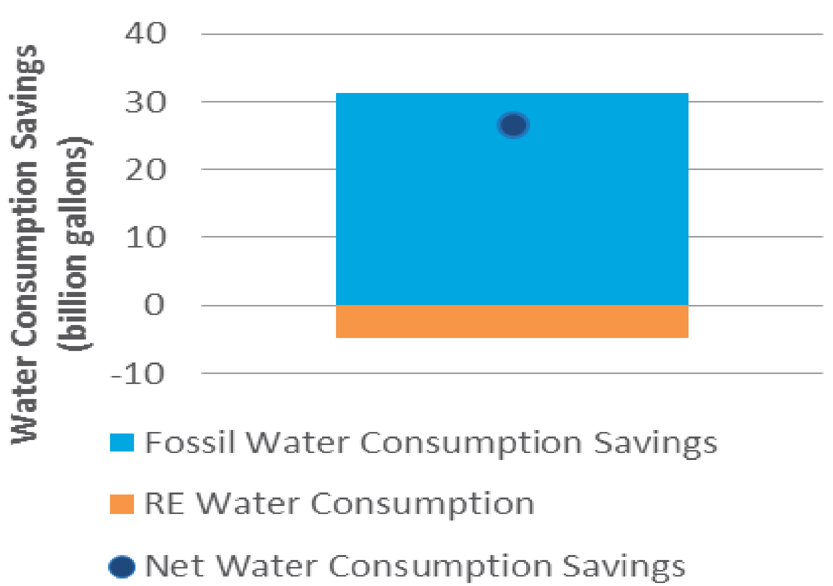
Summary of Key Results: Physical Impacts

Reduced net national water withdrawals by 830 billion gallons and net national water consumption by 27 billion gallons

Withdrawal



Consumption



Reductions = 2% of power sector water withdrawals and consumption

Each MWh of RE serving RPS represents average savings of 8,420 gallons of water withdrawal and 270 gallons of consumption

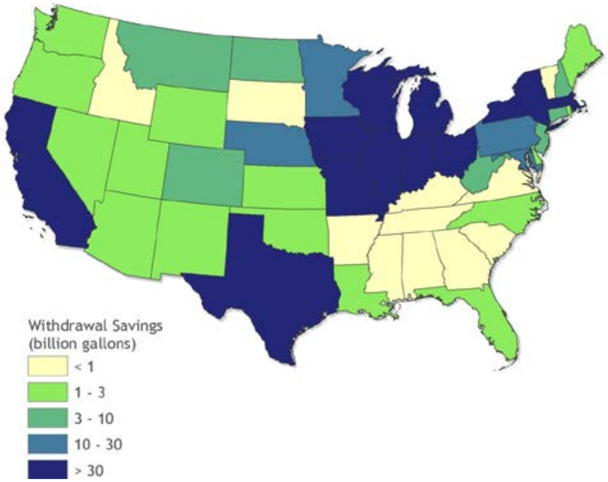
Summary of Key Results: Details on Benefits

NREL NATIONAL RENEWABLE ENERGY LABORATORY | BERKELEY LAB

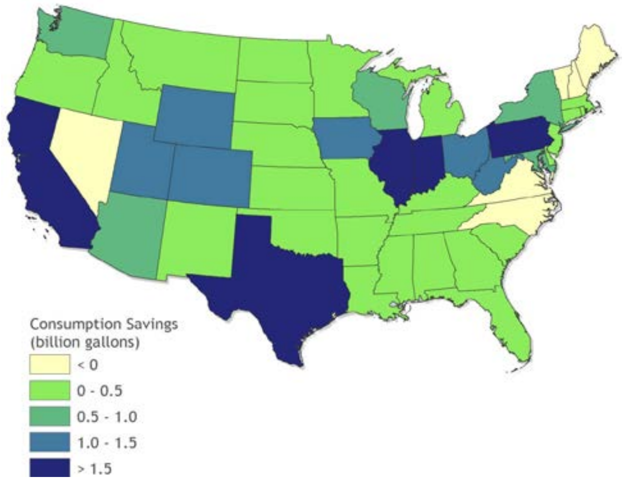
Water savings lower in summer because RE displaces less water-intensive technologies and because some RE with higher water use produce more electricity; water savings predominantly from freshwater sources

Regional water savings are not uniform: impacted by amount, location, and type of RE generation, and by location and type of fossil displacement

Withdrawal



Consumption



There are reductions in water use in many drought-prone regions, with the largest withdrawal savings in California, and the largest consumption savings in Texas

Small number of states see small increases in water withdrawal or consumption

Summary of Key Results: Monetary Benefits

Standard methods do not exist to value—in monetary terms—water use benefits, but water use reductions can be considered a co-benefit of RPS policies, especially where water is scarce

- 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
- Frees water for other uses, whether for other productive purposes or to strengthen local ecosystems
- By avoiding upstream water demands from fossil fuel supply, RE can help alleviate other energy-sector impacts on water resource quality and quantity

Gross Jobs and Economic Development Impacts

David Keyser

Background

- Renewable electricity generation infrastructure requires workers and expenditures
  - Onsite, supply chain, induced
- Research has sought to quantify the gross and net impacts of RE deployment on jobs and economic development
  - Typically finds that RE increases gross jobs related to the RE sector, but evidence and underpinnings for any "net" impacts are limited at national scale
    - RE directly displaces demand for other sources of electric generation
    - Impacts on cost of energy can 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 national level
- We estimate the potential gross, domestic jobs and other economic impacts supported by RPS policies: can provide valuable information about how RE expenditures translate to gross jobs, domestic product, earnings and economic activity—*but <u>do not</u> reflect societal benefits*

Methods and Caveats

Renewable generation serving RPS programs in 2013 and average annual construction from 2013 through 2014

↓

JEDI models and IMPLAN

↓

Gross jobs, earnings, output, and GDP impact estimates

JEDI used for all estimates, except for landfill gas, where IMPLAN is used instead; costs and assumptions for "domestic content" largely based on JEDI default data

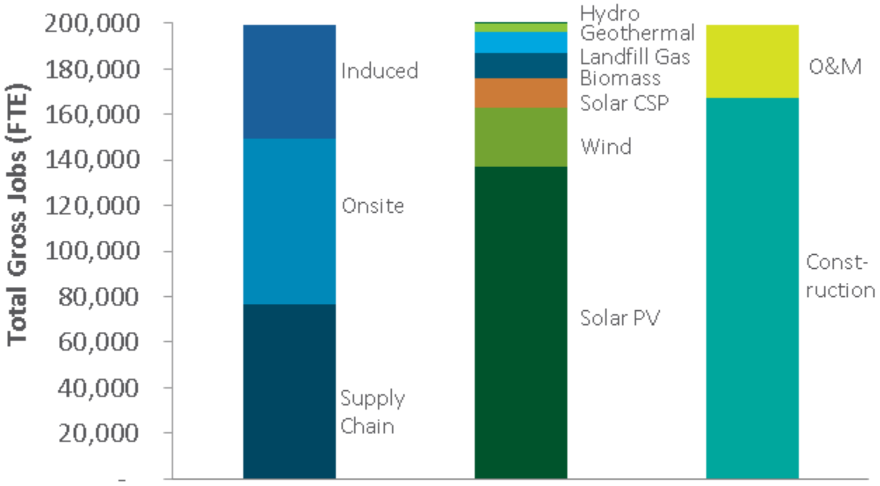
- Results are reported based on onsite, supply chain, and induced impacts, for both operation and construction; results presented on a national and, for onsite jobs only, state-by-state basis
- All results produced by JEDI and IMPLAN are for the equivalent of a single year—O&M jobs can be assumed to be ongoing, however, while construction jobs are inherently limited
- Estimates represent gross impacts: do not reflect other potential economic impacts such as displaced fossil plants, changes in utility electricity rates, or changes in property values or other prices—results should not be considered net economy-wide impacts or societal benefits
- Several aspects of methodology may produce uncertainties or inconsistencies (see full report)

Summary of Key Results: Physical Impacts

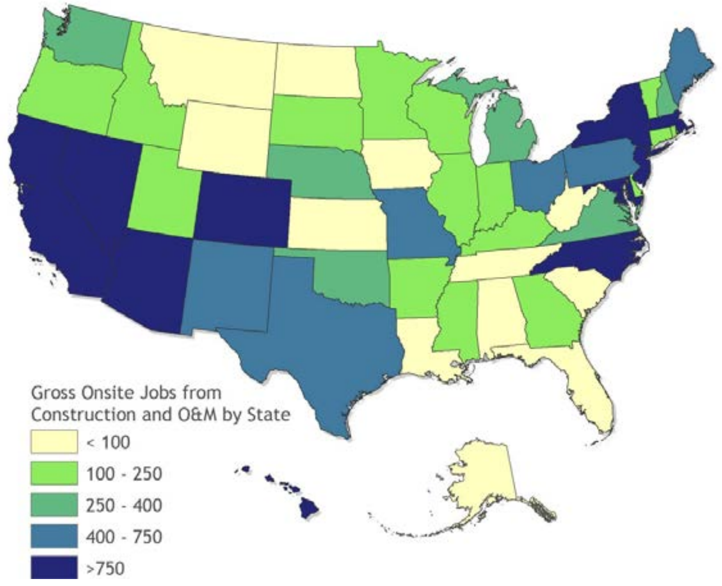
Supported nearly 200,000 gross domestic jobs in 2013, each earning an average annual salary of $60,000, with RE expenditures driving over $20 billion in gross GDP

Location of onsite jobs greatly impacted by new build in 2013-2014 (dominated by PV in California, but including a number of other prominent states noted in map below)

Gross Total Jobs



Gross Onsite Jobs

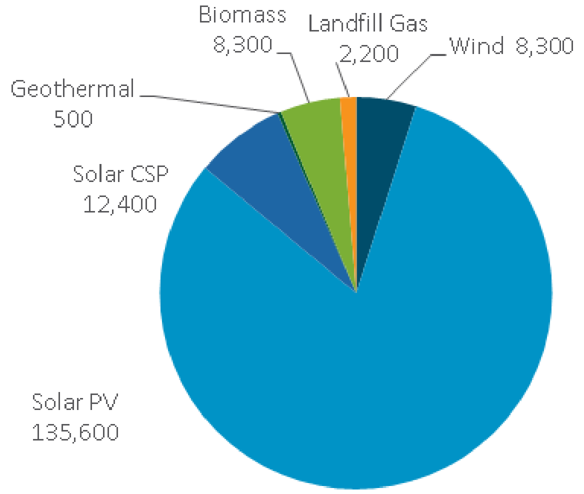


Summary of Key Results: Details on Impacts

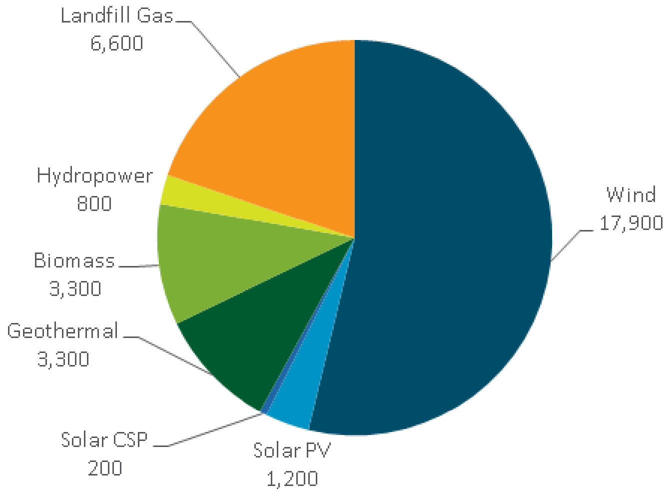
Distribution of jobs among RE technologies reflects the contribution of each technology to RPS generation and capacity additions, as well as its labor-intensiveness within the construction and operation phases

Gross Jobs Supported by RPS by Technology

Construction



O&M



Wholesale Electricity Price Reduction Impacts

Andrew Mills

Background

- RE (with a low marginal cost of energy) "pushes out" the wholesale power supply curve, an impact referred to as the merit-order effect
- In the short run—within the time it takes generation to be built or retire—this shift of the supply curve reduces market clearing prices (in the longer term, effect decays towards zero)
- Lower wholesale market prices can also lead to lower consumer electricity bills to the extent that utilities purchase at these prices
- We quantify the potential effects of RPS' on wholesale electricity prices and estimate the associated cost savings to consumers
- It is important to recognize, however, that these savings to electricity consumers come at the expense of electricity generators: *the RPS-induced reduction in wholesale prices represents a transfer of wealth from generators to consumers rather than a net societal benefit*

Methods and Caveats

Estimate supply curves relating electricity demand to wholesale prices (AVERT)

Generate "unadjusted" wholesale prices for each region with and without RPS generation

Adjust the wholesale price effect by a decay factor and the portion of demand purchased at spot market prices

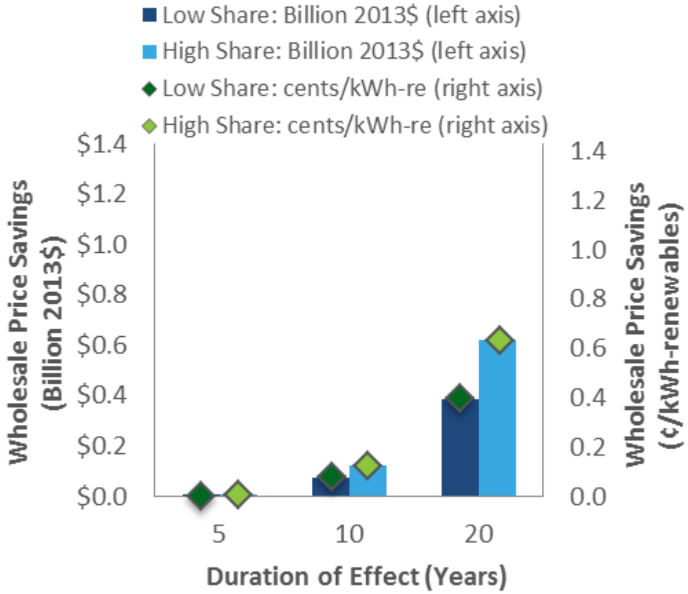
- Consumer benefits calculated here represent a wealth transfer from electricity generators to consumers: no net societal benefit is claimed
- Accuracy of the decay factor is uncertain, both in terms of timing (e.g., whether decay starts when RPS is enacted or RE generator is built) and rate of decay (e.g., 5, 10, or 20 years): we therefore apply a wide range of assumptions, yielding a similarly wide range of imprecise impact estimates
- Most electricity consumers are not fully exposed to wholesale price changes: we present a range of results assuming that either a low or high share of purchases are based on the wholesale price (see report for details)

Summary of Key Results: Monetary Impacts

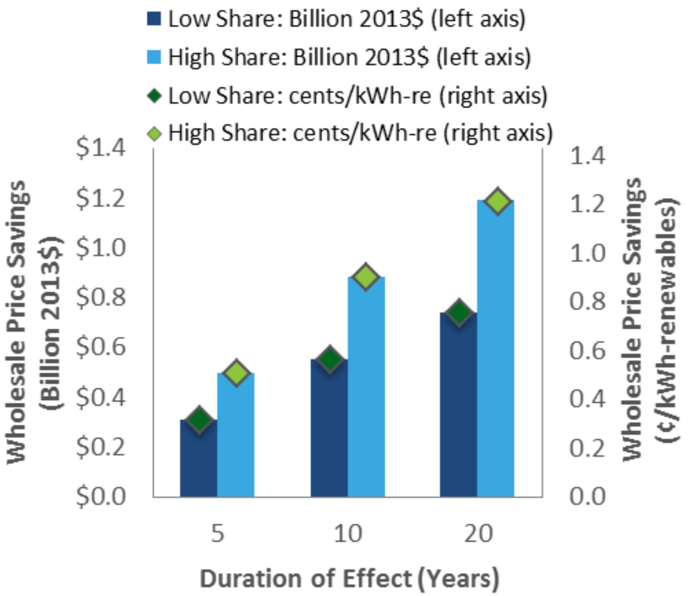
Aggregate, national consumer savings resulting from wholesale price reductions are estimated to range from $0.0 to $1.2 billion

Uncertainty consistent with range of assumptions used for decay of price effects and portion of retail electricity purchased at spot market

RPS Vintage



RE Project Vintage



Consumer savings are equivalent to: 0.0-1.2¢/kWh-renewable

Natural Gas Price Reduction Impacts

Mark Bolinger

Background

- Renewable energy sources are frequently noted to have lower fuel price risks than fossil energy supplies
- Standardized tools for quantifying the full benefits of fuel risk reduction do not yet exist, but the increased use of RE does mitigate risks in one way that can be quantified: RE displaces gas-fired generation, reducing demand for natural gas and thereby placing downward pressure on natural gas prices
- We estimate the potential effect of RPSs on natural gas prices and energy bills, recognizing that the reduction in gas prices can benefit consumers in all natural gas-consuming sectors of the economy
- It is important to recognize, however, that these savings to consumers come at the expense of natural gas producers: *the RPS-induced reduction in natural gas prices represents a transfer of wealth, not a net societal benefit, at least at a national level*

Methods and Caveats

Derive "inverse price elasticity of natural gas supply" curve from the EIA's NEMS

↓

Apply elasticity curve to RPS-induced natural gas displacement in 2013 (AVERT)

↓

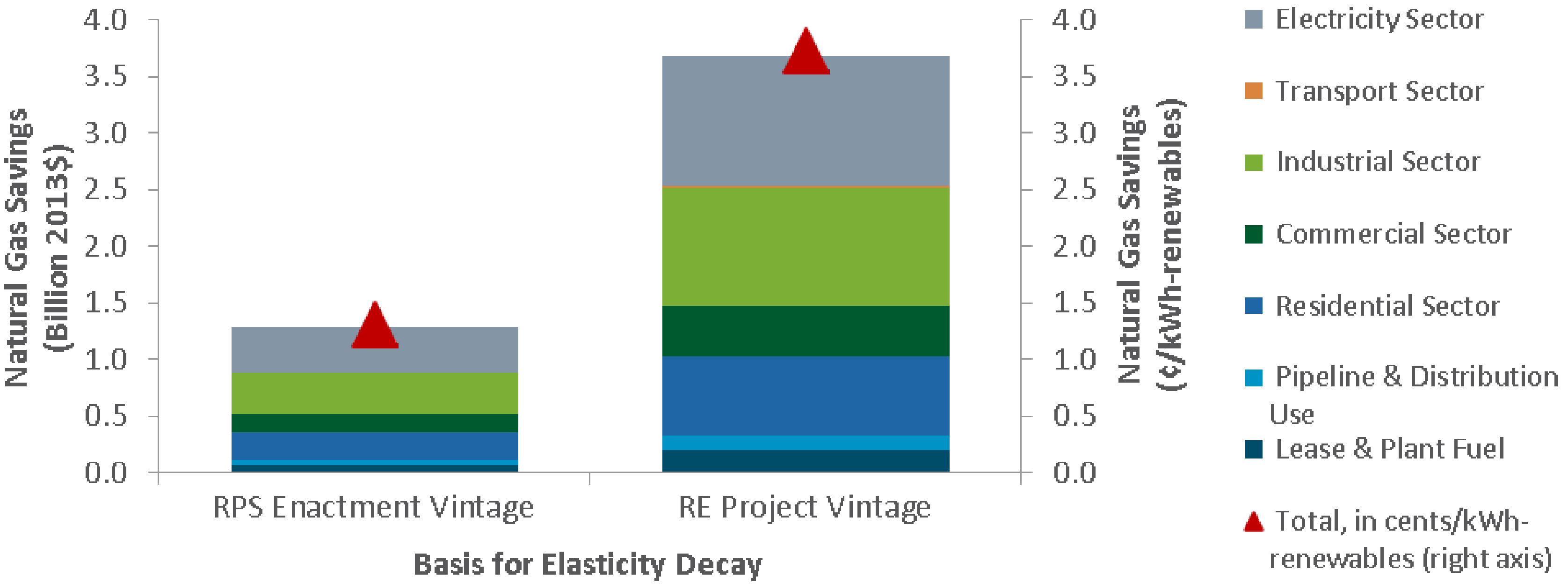
Apply resulting natural gas price change to nationwide gas demand in 2013 (EIA)

- Consumer benefits calculated here represent a wealth transfer from producers to consumers: no net societal benefit is claimed, at least nationally
- Though roughly consistent with past literature, 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
- Uncertainty over whether decay should begin on the date of RPS enactment or once RE generators have been built: we bound this uncertainty by presenting a range of results book-ended by these two extremes
- Assume that national average wellhead price changes flow through fully to delivered gas prices in all states and sectors; assume that consumers are 100% exposed to wellhead price changes
- Do not account for possible rebound effect whereby gas price reductions spur additional demand

Summary of Key Results: Monetary Impacts

Reduced demand for natural gas by 0.42 quads, representing 1.6% of total consumption in U.S.: lowered gas prices by \$0.05 to \$0.14/MMBtu, depending on when decay begins

When applied to all gas-consuming sectors of the economy, aggregate consumer savings in 2013 range from \$1.3 billion to \$3.7 billion

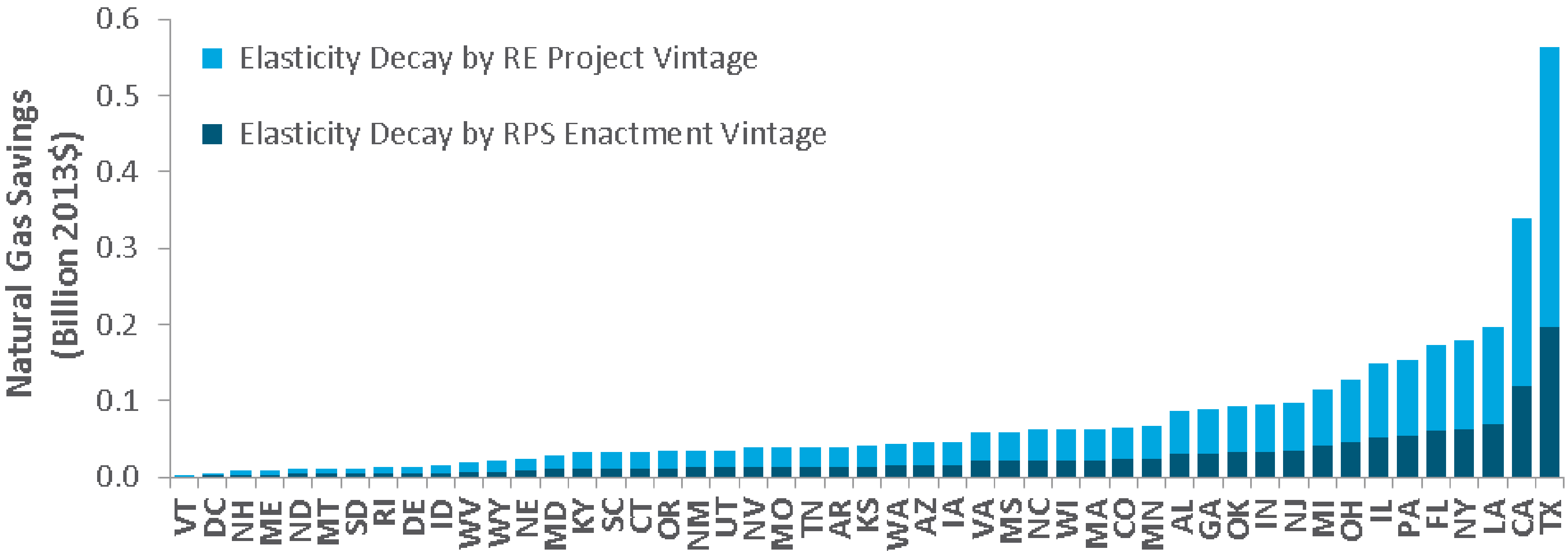


Consumer savings are equivalent to: 1.3-3.7¢/kWh-renewable

Summary of Key Results: Details on Impacts

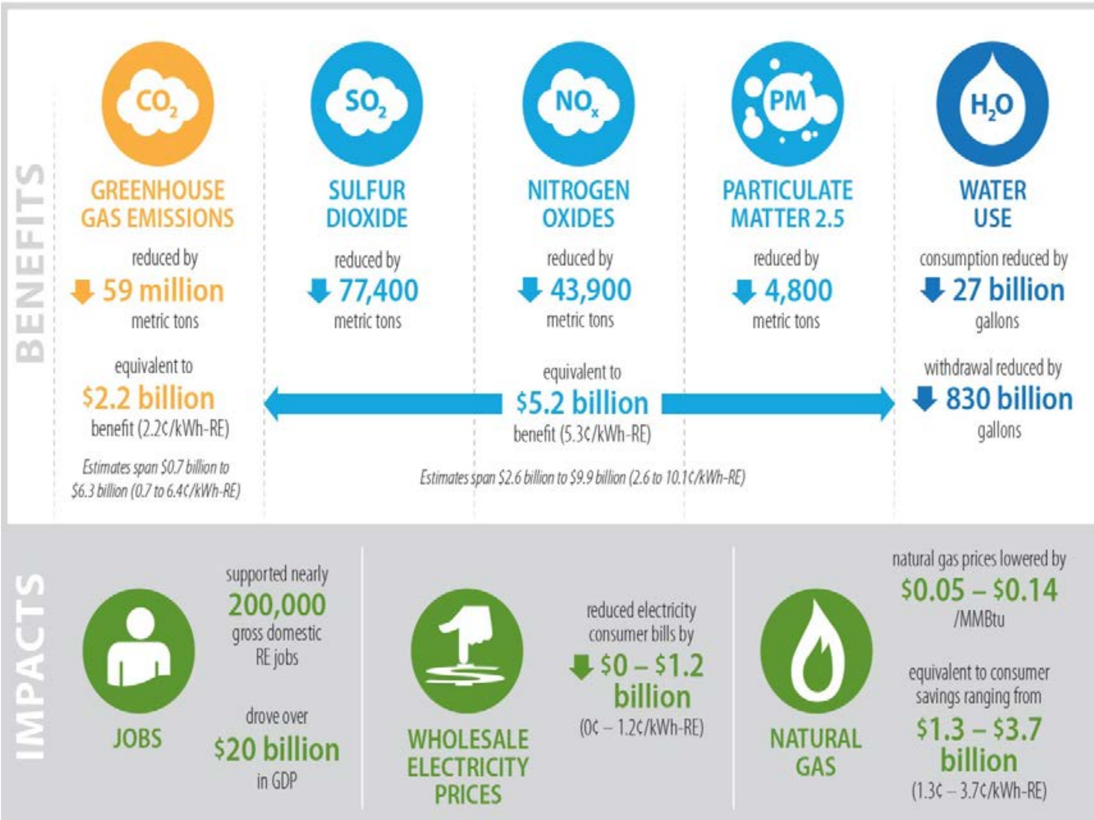
State-level consumer savings vary widely based on amount of state-level natural gas demand, with largest savings in TX, CA, LA, NY, FL, PA, IL (not driven by location of RPS, but instead location of natural gas demand)

Some of the largest state beneficiaries—e.g., TX, LA, PA—also happen to be large gas-producing states, so those states are also impacted by the offsetting negative effect on natural gas producers



Conclusions

Summary of Results: 98 TWh of New RE Meeting RPS Obligations in 2013 Yields…



Note: This study evaluated a subset of the potential benefits and impacts of state RPS policies. We distinguish impacts from benefits, because we do not estimate or claim any net social benefit from the impacts assessed here. We do not assess all potential benefits and impacts, for example land use and wildlife impacts, or job losses in the fossil industry. We also do not address the costs of state RPS programs, as that was the subject of an earlier study (Heeter et al. 2014).

- Sizable uncertainty, but benefits of GHG and air pollution emissions reduction total ~$7.4 billion in 2013, or 7.5¢/kWh-RE, using central estimates
- Previously-estimated average aggregate compliance cost of state RPS programs from 2010-2013 = ~$1 billion/year (Heeter et al. 2014)
  - More work needed for rigorous comparison

Developed methodology that states can build upon & refine for their own analyses: methods, assumptions, caveats all documented in report

For More Information...

Report, factsheet, and briefing available at:

- https://emp.lbl.gov/publications/retrospective-analysis-benefits-and
- http://www.nrel.gov/docs/fy16osti/65005.pdf

Contact the report's primary authors:

- Ryan Wiser, LBNL: rhwiser@lbl.gov
- Galen Barbose, LBNL: glbarbose@lbl.gov
- Jenny Heeter, NREL: jenny.heeter@nrel.gov
- Trieu Mai, NREL: trieu.mai@nrel.gov