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Renewable Electricity Benefits Quantification Methodology: A Request for Technical Assistance from the California Public Utilities Commission

Technical Report
NREL/TP-6A2-45639
July 2009

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List of Acronyms

BAU	business as usual
BenMAP	Environmental Benefits Mapping and Analysis Program
BLM	U.S. Department of the Interior, Bureau of Land Management
C-R	concentration-response
CARB	California Air Resources Board
CEC	California Energy Commission
COBRA	Co-Benefits Risk Assessment Model
CPUC	California Public Utilities Commission
CSP	concentrating solar power
DOE	U.S. Department of Energy
DOER	Massachusetts Division of Energy Resources
EEPS	Energy Efficiency Portfolio Standard
eGRID	Emissions & Generation Resource Integrated Database
EIA	Energy Information Administration
EPA	U.S. Environmental Protection Agency
ERC	Environmental Review Commission of the North Carolina General Assembly
GREET	Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation
GSP	gross state product
I-937	State of Washington Initiative 937
I-O	input-output
IPM	Integrated Planning Model
IRP	integrated resource plan
JEDI	Jobs and Economic Development Impacts Model
MARKAL	Market Allocation Model
MW	megawatts
NE MARKAL	New England Market Allocation Model
NEMS	National Energy Modeling System
NESCAUM	Northeast States for Coordinated Air Use Management
NPV	net present value
NREL	National Renewable Energy Laboratory
NYSERDA	New York State Energy Research and Development Authority
O&M	operations and maintenance
PM	particulate matter
PPA	power purchase agreement
PV	photovoltaics
ReEDS	Regional Energy Deployment System
REMI	Regional Economic Models, Inc.

RFP	request for proposal
RGGI	Regional Greenhouse Gas Initiative
RPO	regional planning organization
RPS	renewable portfolio standard
TAP	technical assistance project
TEPC	Texas Energy Planning Council
TREIA	Texas Renewable Energy Industries Association
VOC	volatile organic compound
WRAP	Western Regional Air Partnership

Executive Summary

The California Public Utilities Commission (CPUC) requested assistance in identifying methodological alternatives for quantifying the benefits of renewable electricity. The context is the CPUC's analysis of a 33% renewable portfolio standard (RPS) in California—one element of California's Climate Change Scoping Plan.[1] The information would be used to support development of an analytic plan to augment the cost analysis of this RPS (which recently was completed). The National Renewable Energy Laboratory (NREL) has responded to this request by developing a high-level survey of renewable electricity effects, quantification alternatives, and considerations for selection of analytic methods. This report addresses economic effects and health and environmental effects, and provides an overview of related analytic tools. Economic effects include jobs, earnings, gross state product, and electricity rate and fuel price hedging. Health and environmental effects include air quality and related public-health effects, solid and hazardous wastes, and effects on water resources.

Economic Impact

The implementation of an RPS typically has associated economic impacts that include jobs, earnings, and gross state product (GSP). Some industries are impacted more directly than others, depending on the source of materials and labor used in the construction and operation of a renewable energy power-generation facility, but those direct impacts typically filter through the economy through indirect[2] and induced[3] impacts. Assuming that an RPS works as intended, the economic development impacts can vary by state depending on how property taxes, income taxes, and excise taxes figure into the state's fiscal mix.[4]

Two important considerations for measuring economic impact within a state are whether the RPS allows for the eligibility of out-of-state renewable resources, and the share of in-state resources (local share) used for manufacturing of materials and the construction and operation of the renewable-energy facilities. These factors help determine how much of the economic impact will occur in-state vs. out-of-state. State policy makers might have to prioritize between local economic growth and minimizing ratepayer impacts if the most cost-effective renewable resources are in a neighboring state. Extending RPS eligibility to out-of-state resources can reduce ratepayer impacts, but it involves letting another state realize the local economic-development benefits associated with those resources (Hurlbut 2008).

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[1] The California Climate Change Proposed Scoping Plan was approved at the December 12, 2008, meeting of the California Air Resources Board. The document still is titled "Climate Change Proposed Scoping Plan," but now is considered final. The word "Proposed" consequently was dropped from the document's name as used in this document. The document is available at http://www.arb.ca.gov/cc/scopingplan/document/scopingplandocument.htm (accessed April 22, 2009).

[2] Indirect impacts refer to the changes in inter-industry purchases resulting from changes in direct final demand (i.e., purchases of goods and services).

[3] Induced impacts refer to the changes that occur in household spending as household income increases or decreases as a result of the direct and indirect effects from changes in direct final demand (i.e., purchases of goods and services).

[4] A comprehensive assessment is beyond the scope of this analysis, but anecdotal results are indicative of what can happen. The West Texas community of McCamey, where Texas' first wind boom took place in 2001 and 2002, is one example. In 2000, the local property-tax base funding the McCamey Independent School District was just more than $328 million in total assessed valuation. By 2006, with 760 MW of new wind power in operation on nearby mesas, the tax base had increased by more than $1 billion. Additionally, taxable sales receipts in the area doubled from 2002 to 2005. See School and Appraisal Districts' Property Value Study, various years, available at http://www.cpa.state.tx.us/taxinfo/proptax/ (accessed April 23, 2009).

The current body of analysis includes an assortment of studies, both on the state and national RPS level, which estimate economic impacts of an RPS. Many of these studies include economic impact as a component of a bigger picture to measure overall impacts. The studies can be divided into two main types: (1) those that use input-output (I-O) models of the economy; and (2) those that use simpler, largely spreadsheet-based analytical (in some cases econometric) models (Kammen et al. 2004). A simplifying assumption in several of the models is to attribute all renewable energy development over the impact period to the RPS rather than attempting to factor out the development that would have occurred without an RPS.

There is a wide variety of approaches to take in evaluating the economic impact of an RPS. Analysis methodology can range from creating a spreadsheet to employing several discrete models evaluating specific impacts or even to the development of a more comprehensive, complex model. There are several considerations when deciding on an approach, including the key impacts to measure, data availability, and important considerations of the analysis (e.g., gross versus net impacts; in-state (local share) versus out-of-state renewable resources and manufacturing availability to meet RPS goals; and the allocation of renewable energy development attributed to the RPS).

Health and Environmental Effects

Renewable electricity development to meet an RPS will have a variety of health and environmental effects including changes in releases of pollutants to the air, water, or land; and the health or environmental implications of those releases. Among the many health and environmental effects, methods to quantify health effects of air pollution are especially well-developed.

Our overview of the growing set of state-level analytic studies on health and environmental effects of renewable electricity generation in the United States reveals that diverse methods have been used, including a number of different computer models. Different methods and models have distinct advantages and disadvantages, and the choice of a particular method or model will depend on the purpose of the study.

Development of the scope of an analysis of health and environmental effects of an RPS is a significant undertaking. The scope must be tailored to the primary purpose of the study. Scoping decisions include selection of the analytic period, spatial and temporal scale, technology life cycle, and electric generation scenarios. The study must focus on selected environmental releases and effects of those releases.

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I. Introduction

The California Public Utilities Commission (CPUC) submitted a Technical Assistance Project (TAP) Request for national laboratory assistance to the U.S. Department of Energy (DOE), identifying different options for methods of quantifying the benefits of renewable electricity. The core of this request is as follows.

> **TAP Request:** Develop a methodology to quantify the benefits of an RPS [renewable portfolio standard]. We already have a methodology to quantify avoided costs of natural gas fuel purchases and avoided investments in fossil infrastructure. We would like to develop a methodology to quantify other benefits, such as fuel diversity/hedging value, health benefits/avoided criteria pollutants, other environmental benefits, and economic development (even though that isn't technically a benefit). We would like this work to be within the context of the current cost analysis CPUC staff are for a 33% RPS (you can view our work plan here: http://www.cpuc.ca.gov/NR/rdonlyres/1C8F102F-53A6-486E-A11E-BAD5DA3FBB9B/0/33_Percent_by_2020_RPS_Draft_Workplan.DOC).
>
> **Goal:** The near-term goal is to evaluate the additional benefits of the CA RPS so that the current cost-benefit analysis will be more inclusive of all the benefits. The long term goal is to guide decision-makers on the appropriate RPS targets. (CPUC 2009)

The California Public Utilities Commission intends to use this information to develop a methodology for a more comprehensive analysis of a 33% renewable portfolio standard (RPS), extending beyond the cost analysis to include other effects. The increase to 33% from a 20% RPS is part of California's Climate Change Scoping Plan (California Air Resources Board 2008).

In this report, the NREL has responded to CPUC's request with a high-level survey of renewable electricity effects, quantification alternatives, and considerations for selection of analytic methods. This report does not select or implement analytic methods. Section III addresses economic effects: jobs, earnings, and gross state product. Section IV addresses electricity and fuel price hedging. Section V addresses health and environmental effects that include air quality and related public health effects, solid and hazardous wastes, and effects on water resources.

II. Background

State renewable portfolio standards have emerged as one of the most important policy drivers of renewable energy capacity expansion in the United States (Wiser et al. 2007). Collectively, these state policies now apply to roughly 50% of U.S. electricity load, and hold the prospect of having substantial impacts on electricity markets, ratepayers, and local economies. Renewable portfolio standards require that a minimum amount of renewable energy is included in each retail electricity supplier's portfolio of electricity resources. This is accomplished by establishing numeric targets for renewable energy supply, which generally increase over time. To date, 28 U.S. states, along with the District of Columbia, have adopted such standards (Figure 1) (Chen et al. 2008).

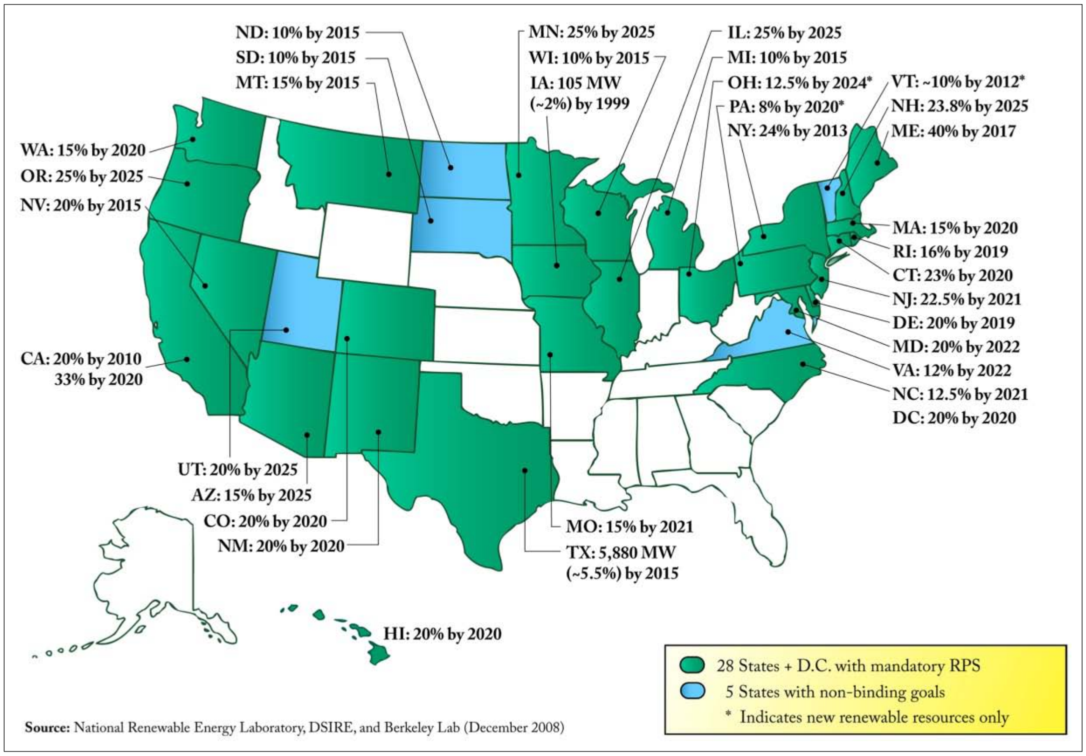

Figure 1. States that have renewable portfolio standards

California

California's RPS was established in 2002 under Senate Bill 1078 and was accelerated in 2006 under Senate Bill 107. It is one of the most ambitious renewable energy standards in the country. The RPS program requires electric corporations to increase procurement from eligible renewable energy resources by at least 1% of their retail sales annually, until they reach 20% by 2010. The California RPS considers wind, solar, biopower, small hydro (less than 30 MW), geothermal, ocean wave, ocean thermal, and tidal current as eligible power-generation sources and, to be counted in the RPS, the power must be actual energy delivered. The CPUC and the California Energy Commission (CEC) recommend 33% renewables by 2020 as a key strategy to reducing greenhouse gas emissions, and the governor's Executive Order S-14-08 (California State 2008) made it an official goal for state agencies.

III. Economic Impact

The implementation of an RPS typically has associated economic impacts that include jobs, earnings, and gross state product (GSP). Some industries are impacted more directly than others, depending on the source of materials and labor used in the construction and operation of a renewable energy power-generation facility, but those direct impacts typically filter through the economy through indirect[5] and induced[6] impacts. Assuming that an RPS works as intended, the

[5] Indirect impacts refer to the changes in inter-industry purchases resulting from changes in direct final demand (i.e., purchases of goods and services).

[6] Induced impacts refer to the changes that occur in household spending as household income increases or decreases as a result of the direct and indirect effects from changes in direct final demand (i.e., purchases of goods and services).

economic development impacts can vary by state depending on how property taxes, income taxes, and excise taxes figure into the state's fiscal mix.[7] A study of Pennsylvania, for example, found that if an RPS succeeded in increasing renewable energy use to 10% of total electricity demand by 2025, the impact on jobs, income, and economic output would be significantly greater than that expected if load growth and unit retirements during that same time instead were met by fossil-fuel expansion (Pletka et al. 2004).

Two important considerations for measuring economic impact within a state are whether the RPS allows for the eligibility of out-of-state renewable resources, and the share of in-state resources (local share) used for manufacturing of materials and the construction and operation of the renewable-energy facilities. In either case, economic-impact leakages to other states could occur. State policy makers might have to prioritize between local economic growth and minimizing ratepayer impacts if the most cost-effective renewable resources are in a neighboring state. Extending RPS eligibility to out-of-state resources can reduce ratepayer impacts, but it involves letting another state realize the local economic-development benefits associated with those resources (Hurlbut 2008).

The current body of analysis includes an assortment of studies, both on the state and national RPS level, which estimate economic impacts of an RPS. Many of these studies include economic impact as a component of a bigger picture to measure overall impacts. The studies can be divided into two main types: (1) those that use input-output (I-O) models of the economy; and (2) those that use simpler, largely spreadsheet-based analytical (in some cases econometric) models (Kammen et al. 2004). A simplifying assumption in several of the models is to attribute all renewable energy development over the impact period to the RPS rather than attempting to factor out the development that would have occurred without an RPS.

Several studies which specifically address economic impacts are listed in Table 1. Some of the newer, more comprehensive studies are described below for consideration in developing a California-specific methodology (full references to these studies can be found in the bibliography presented in Appendix A) (Chen et al. 2008). In the description below, some background is provided to frame the discussion, high-level results are presented, and analytical methods are described. In most cases these descriptions are taken directly from the respective report. Some descriptions are more detailed than others depending on relevance and availability of information. Assumptions for local share are addressed when available because of their direct relevance to the question posed by the TAP, but other assumptions are not discussed as they vary widely among the studies, the states and the RPS structure. The purpose of this section is to present different methodological approaches and give examples of results. The results reported in these studies are not directly comparable because of the varying assumptions and methodologies of each study. In developing an approach to evaluate the impacts of an RPS in California, it will be of key importance to review the studies in more depth to determine the direction, assumptions, and approach for a California-specific methodology.

[7] A comprehensive assessment is beyond the scope of this analysis, but anecdotal results are indicative of what can happen. The West Texas community of McCamey, where Texas' first wind boom took place in 2001 and 2002, is one example. In 2000, the local property-tax base funding the McCamey Independent School District was just more than $328 million in total assessed valuation. By 2006, with 760 MW of new wind power in operation on nearby mesas, the tax base had increased by more than $1 billion. Additionally, taxable sales receipts in the area doubled from 2002 to 2005. See School and Appraisal Districts' Property Value Study, various years, available at http://www.cpa.state.tx.us/taxinfo/proptax/ (accessed April 23, 2009).

Table 1. Sampling of Studies that Address Economic Impacts from an RPS

State	Produced by	Publish Year	Jobs	Gross State Product (GSP)	Income	Reviewed Below?
AZ	AZ PIRG Education Fund	1998	x	x	x	No
AZ	American Solar Energy Society	2005	x		x	No
CO	Union of Concerned Scientists	2004	x	x	x	Yes
MI	Next Energy	2007	x	x	x	No
NC	La Capra, GDS and Sustainable Energy Advantage	2006	x			Yes
NE	Union of Concerned Scientists	2001	x	x	x	No
NH	University of New Hampshire	2007	x			No
NJ	The State University of NJ (Rutgers)	2004	x	x	x	No
NY	KEMA, Inc. and Econ. Development Research Group	2008	x	x	x	Yes
PA	Black and Veatch	2004	x	x	x	Yes
TX	Union of Concerned Scientists	2005	x	x		Yes
WA	Union of Concerned Scientists	2006	x	x	x	Yes
WI	Union of Concerned Scientists	2006	x	x	x	Yes

IV. Electricity Rates and Fuel Price Hedging

Two types of hedging or risk mitigation are addressed in the literature most prominently: electricity rate and fuel price hedging. Although the existing body of analysis is not as robust for hedging impacts from an RPS as for economic impact, there are several studies which address the topic (listed in Table 2). Several of the studies which cover electricity or fuel price hedging are the same as those that cover economic impacts, and are discussed below as noted in Table 2. An additional study—which does not address economic impact but does estimate a hedge adder—includes a natural gas price adder to correct for "downward bias" of EIA forecasts and also models electric rate impacts of "NG price spike" sensitivity scenario. This study was conducted for Colorado by Public Policy Consulting and also is described below.

Table 2. Sampling of Studies that Address Fuel Price and/or Electricity Price Hedging Impacts of an RPS

State	Produced by	Publish Year	Wholesale price	Gas price	Hedge adder
CO	Public Policy Consulting*	2004			x
CO	Union of Concerned Scientists*	2004	x	x	
NH	University of New Hampshire	2007		x	x
NY	Center for Clean Air Policy	2003	x	x	
NY	NY State Department of Public Service, Sustainable Energy Advantage and La Capra Associates	2004	x		
NY	ICF Consulting	2003	x	x	
NY	Potomac Economics	2005	x		
PA	Black and Veatch*	2004			x
TX	Union of Concerned Scientists*	2005	x	x	

*Discussed further below

Models Employed in the Studies

Several different models were employed in the studies profiled. Table 3 lists some of the models and includes a description and some pros and cons for each model.

Table 3. Sampling of Models Employed in Studies Profiled

Model Name	Availability	Model Description	Pros and Cons
IMPLAN (Impact Planning)	Software available for purchase through MIG & Associates (http://www.implan.com/)	IMPLAN is an economic impact assessment software system. IMPLAN allows the user to develop models of local economies to estimate a wide range of economic impacts from a one-time or sustained increase in economic activity in a given geographic area.	Pro: Effective and widely used tool to estimate economic impact. Cons: Learning curve associated with the software; cost associated with acquiring the software. Must use this software with an estimate of the increase in economic activity in a particular industry.
JEDI (Jobs and Economic Development Impact)	Available for free download at http://www.nrel.gov/analysis/jedi/about_jedi.html	JEDI is an input-output model which estimates the economic impact—including jobs, earnings, and output—to the economy from the construction and operation of a renewable energy power-generating facility. There are also versions of JEDI for biofuels facilities. JEDI estimates project development and on-site impacts, manufacturing and supply chain impacts, and induced impacts.	Pros: Stand-alone, user-friendly, Excel-based model is available for free download. Minimal learning curve associated with learning how to use the model. Provides default cost input assumptions which user easily can override. Local share can be explicitly stated as a model input. Output is clear and concise. Cons: Renewable energy–project specific; assumptions must be made about the ramp-up of particular renewable energy technologies and the related size of facilities to be constructed. Reports gross, rather than net, impacts.

Model Name	Availability	Model Description	Pros and Cons
NEMS (National Energy Modeling System)	For more information see http:// www.eia.doe.gov/ oiaf/aeo/ overview/	NEMS is a computer-based, energy-economy modeling system of U.S. energy markets for the midterm period through 2025. NEMS projects the production, imports, conversion, consumption, and prices of energy. The results are subject to assumptions on macroeconomic and financial factors, world energy markets, resource availability and costs, behavioral and technological choice criteria, cost and performance characteristics of energy technologies, and demographics. NEMS was designed and implemented by the Energy Information Administration (EIA) of the U.S. Department of Energy (DOE).	NEMS is a model run by DOE and output is made available in the Annual Energy Outlook. Output from NEMS can be used as inputs for economic modeling. Pros: Comprehensive framework for modeling energy usage across all sectors in the United States. Cons: Does not include sufficient geographic detail to model many issues of renewable electricity generation. Extreme cases with high renewable electricity penetration are difficult to model.
RIMS (Regional Input-Output Modeling System)	Software available for purchase through Bureau of Economic Analysis (http://www.bea.gov/ regional/rims)	RIMS II multipliers attempt to estimate how much a one-time or sustained increase in economic activity in a particular region will be supplied by industries located in the region. RIMS II provides six types of multipliers: Final-demand multipliers for output, earnings, employment, and value added; and direct-effect multipliers for earnings and employment. The multipliers can be ordered for any user-defined region or for any RIMS II industry.	IMPLAN and RIMS are multiplier-based models so the pros and cons for IMPLAN apply to RIMS.

Colorado (2004) (Electricity Rate Hedging Only)

Public Policy Consulting (PPC) prepared this report to estimate the effect that an RPS will have on the retail rates of the affected Colorado utilities. Using the RPS requirements contained in HB 1273, introduced in the 2004 Colorado General Assembly, the report first estimates the amount of renewable energy that would be obtained by Colorado's two investor-owned utilities over the next 20 years. The analysis then compares the cost of renewable energy with new fossil-fueled generation to estimate the effect that the RPS requirement will have on retail electric rates. The report examines the degree to which renewable resources can act as a hedge against price fluctuations is the natural gas market. PPC found that renewable energy sources can save consumers money by acting as a "hedge" against spikes in natural gas prices. Renewable sources such as wind will result in consumer savings of $0.52 to $0.75 per month (in addition to other savings) in years when natural gas prices spike as they did in 2000 and 2003.

In preparing this report PPC employed two methodologies. First, it conducted extensive research of the research literature on energy-price forecasts, on renewable portfolio standards (including studies from other states that estimated the rate impact of an RPS), and on the current state of generation technologies. Next, the 20-year future of retail electric prices for Colorado's investor-owned utilities were modeled, estimating the avoided cost against which the estimated future costs of renewable energy can be compared. The report computes the difference between the future price of renewables (assumed to be wind power, for analytic purposes) and the future cost of electricity produced with fossil fuels (assumed to be advanced combined-cycle natural gas-fired generation).

In addition to offering point estimates of the impact of renewable portfolio standard on retail electric rates, the report also examines the sensitivity of the analysis to certain key variables, including the cost of natural gas and changes in federal tax policy. Finally, the report simulates the change in electric prices caused by spikes in natural gas prices, similar to those that occurred in 2000 and 2003. This last analysis enables measurement of the "hedge" value of some renewable resources.

Colorado (2004)

Union of Concerned Scientists (UCS) evaluated Colorado's Amendment 37 in 2004. At that time, Colorado's Amendment 37 provided the first opportunity for citizens in any state to vote on these policies directly. Amendment 37 passed overwhelmingly, and established a renewable energy standard requiring the state's utilities with more than 40,000 customers to generate or acquire renewable energy equal to at least 3% of retail sales by 2007, increasing to 6% in 2011 and to 10% in 2015, and then remaining at 10% each year thereafter.[8] The amendment also established a funding mechanism for solar energy, giving a rebate to building owners who install solar energy systems. This is similar to funding mechanisms established in many of the state renewable energy funds.[9]

Under the most-likely scenario that primarily utilizes renewable-energy technology cost projections from the Department of Energy's national labs, UCS found that by 2025 Amendment 37 would result in the following economic benefits for Colorado.

- $236 million in savings on consumer electricity and natural gas bills resulting mostly from reduced natural gas demand and reduced natural gas prices resulting from the increase in renewable energy availability.
- 2,000 new jobs in manufacturing, construction, operation, maintenance, and other industries.
- $70 million in additional income and $50 million increase in gross state product.
- $709 million in new capital investment.
- $15 million in income to rural landowners from wind power land leases.
- $107 million in new property tax revenues for local communities.[10]

For the macroeconomic analysis, UCS used the Impact Analysis for Planning (IMPLAN)[11] model and specific data on Colorado's economy to estimate the macroeconomic impacts (employment, income, gross state product) of the Colorado renewable energy standard.[12] MRG & Associates conducted this portion of the analysis. IMPLAN is an input-output (I-O) model that identifies interactions between all sectors of the economy. Input-output models can show how expenditures for installing, manufacturing, operating, and maintaining renewable energy technologies and related equipment not only directly benefit the industries engaged in these activities, but also indirectly benefit businesses that provide inputs (i.e., goods, services) to these industries. This type of model also can show the benefits of workers spending the income earned

[8] The full text of the renewable energy standard ballot initiative can be viewed at http://www.dsireusa.org/documents/Incentives/CO26R.htm (accessed April 23, 2009).
[9] Fifteen states have enacted renewable energy funds which provide financial resources for renewable energy development.
[10] Results are in cumulative net present value in 2002 dollars, using a 7% real discount rate. Job results are for the year 2020.
[11] IMPLAN is a software program which can be purchased from MIG & Associates. For more information, visit http://www.implan.com/ (accessed April 23, 2009).
[12] The analytical approach used in this analysis is similar to that used by Geller, DeCicco, and Laitner (*Energy Efficiency and Job Creation*, 1992, Washington DC: American Council for an Energy-Efficient Economy).

from these direct and indirect activities, and the impact of changes in consumer energy bills. There were four main steps to completing the macroeconomic analysis.

- First, total expenditures were estimated for installing, manufacturing, operating, and maintaining renewable energy technologies that are projected to be developed to meet the Colorado renewable energy standard and for coal and natural gas power plants that would have been developed without the standard.
- Second, the expenditures were broken down and allocated to the industries that would directly supply the equipment, labor, and services for these technologies.
- Third, the detailed expenditures were multiplied by the estimated local share of equipment, labor, and services that could be supplied by Colorado businesses and matched to the appropriate sectors in the IMPLAN model to calculate the direct and indirect macroeconomic impacts in Colorado.
- Finally, the macroeconomic impacts of changes in consumer energy bills in Colorado were calculated.

The key assumptions and data sources for the macroeconomic analysis include the following.

- The expenditure breakdown for the construction and operation and maintenance of renewable and conventional power plants was based on data from actual projects collected from a variety of sources, including state and federal agencies, renewable energy developers, and utilities. The expenditure breakdown and local share data on wind projects—the technology that benefits most under the renewable standard[13]—was based on inputs used in NREL's Jobs and Economic Development Impacts (JEDI) Model.[14]
- The Union of Concerned Scientists used data from the IMPLAN model to estimate the local share of expenditures for specific industries, with a few exceptions. It assumed that 33% of the manufacturing for the wind and solar technologies installed in Colorado would be produced by businesses located in the state. It does not include any jobs or economic development from Colorado manufacturers exporting equipment to other states or countries. If Colorado is able to attract renewable energy manufacturers to produce equipment for facilities in the state and for export, then the jobs and income from the standard would increase significantly.
- Additionally, it was assumed that 25% of the fuel expenditures for coal and 50% of the fuel expenditures for natural gas are spent on Colorado-based resources and therefore stay in Colorado. This is based on data from EIA (EIA 2009a) and a recent study by NREL (Tegen 2004).

North Carolina (2006)

At its January 24, 2006, meeting, the Environmental Review Commission (ERC) of the North Carolina General Assembly requested that the North Carolina Utilities Commission (Commission) undertake a review of the potential costs and benefits of enacting an RPS in North Carolina. The Commission retained a team of consultants consisting of GDS Associates, Inc.,

[13] Considering the wind resource in Colorado, in areas having the best wind resources wind energy can compete on a lowest-cost resource basis with fossil fuels on a long-term basis.
[14] For more information about the JEDI model, see http://www.nrel.gov/analysis/jedi/about_jedi.html.

Sustainable Energy Advantage, LLC, and La Capra Associates, Inc. (La Capra Team). As discussed in detail below, the key findings of the analysis are as follows.

- North Carolina should have sufficient renewable resources within the state to meet a 5% RPS requirement for new renewable generation. A 5% RPS would increase average retail electricity rates by less than 1% and would be accompanied by net job-creation and property-tax benefits.
- The state would have difficulty meeting a more-aggressive 10% RPS with only new renewable resources located within North Carolina. A 10% RPS focused solely on generation supply only would be achievable by the inclusion of larger hydroelectric generation and the development of wind in both the western part of the state and at off-shore locations. A 10% RPS met only with new renewable generation would increase average retail electricity rates by at most 3.6% in the tenth year.
- Inclusion of energy efficiency as an eligible RPS resource in addition to larger hydroelectric generation and wind in the western part of the state would enable the state to achieve a 10% RPS and could dramatically reduce the cost of an RPS. If energy efficiency was permitted to comprise 25% of an expanded resources RPS portfolio, for example, both a 5% RPS and a 10% RPS reasonably could be expected to produce total electric cost savings for consumers of about half a billion dollars over 20 years.[15]

A number of steps were necessary to establish the framework of the analysis. These steps include the following.

- Establish different policy scenarios to investigate, and include different RPS targets and eligible resources. Issues that were addressed in designing appropriate scenarios included:
    - The treatment of existing resources;
    - The time frame to be covered by the study;
    - The RPS target or targets to model; and
    - The types of resources that should be included.
- Estimate resource potential (renewable energy and energy efficiency) within the state and the costs associated with each type of resource.
- Develop renewable resource supply curves, assuming that most suppliers would not be utility-owned facilities but instead would be contracted through long-term power purchase agreements (PPAs). The expectation is that lower-cost resources will be developed first.
- Estimate North Carolina's future electric-supply expansion needs based on the state's utility-filed integrated resource plans (IRPs). This is called the utility's portfolio.
- From the supply curves, determine the mix of resources (renewable, energy efficiency, conventional generation) that would fulfill each of the RPS scenarios, and meet future capacity and energy growth.

[15] This is calculated in net present value (NPV) over 20 years using a discount rate of 10%.

- Compare the costs of the alternative RPS portfolios with that of the utilities' portfolios.
- Conduct similar comparisons for sensitivity tests.

New York (2008)

As an aside, this recent report by KEMA, Inc. and Economic Development Research Group for New York State Energy Research and Development Authority (NYSERDA) seems to be the most comprehensive with regard to economic impact analysis of the reports discussed herein, considering direct and indirect impacts as well as impacts associated specifically with various renewable technologies on the facility level.

This report provides an assessment of the total economic benefits that result from NYSERDA's Renewable Portfolio Standard Main Tier program. The analysis used a discrete set of economic measures that covered the facility's construction phase and over the life of the facility. The construction phase was estimated to last for three years (herein referred to as short term) and the "over the life of the facility" phase was estimated to last 20 years (herein referred to as long term).

The economic benefits or effects of these measures were analyzed at two levels—the direct benefits or effects in the economy resulting from the facilities were calculated, and the indirect or multiplier effects were modeled (using an IMPLAN I-O model) throughout other sectors of the economy. These benefits include direct project benefits as well as the indirect—or multiplier induced[16]—benefits to New York's economy. The results were modeled for the three scenarios. One scenario covered the progress to date of the RPS Main Tier and Maintenance Resources Program, as well as two potential scenarios for NYSERDA's Main Tier1 RPS Program. The analysis interval was extended over the 20-year life of a facility. The three scenarios are as follows.

- First three competitive solicitations (RFP 916, RFP 1037, RFP 1168)
- 25% RPS goal by 2013 using the post-energy efficiency portfolio standard (EEPS) (NYPSC 2008)[17] load forecast
- 30% RPS goal by 2015 using the post-EEPS load forecast

Direct benefits reported by developers of wind-, hydropower-, and biofuels-generation facilities include both short-term and persistent long-term impacts. Short-term impacts primarily result from construction jobs and compensation to municipalities, abutting property owners, and some others. Long-term impacts are jobs tied to facility operations and maintenance (O&M); state and municipal revenues (as taxes or payments in lieu of taxes); payments to land owners for land leases; fuel purchases for biofuel facilities; in-state spending on equipment, supplies, and services; and other annual O&M expenses.

The economic measures were estimated and reported by the developers in response to the second and third solicitations issued by NYSERDA for the RPS Main Tier program. KEMA, Inc.

[16] NYSERDA's reference to indirect impact is different from that used by I-O models. For the purposes of the NYSERDA analysis, the indirect impacts include both the wage-spending effects (termed induced), and the supplier transaction (the traditional definition of indirect) effects.

[17] In June 2008, New York enacted an Energy Efficiency Portfolio Standard that seeks to reduce projected energy use by 15% by 2015 (or "15 x 15").

verified the estimates' accuracy, assessed them for credibility, and extrapolated economic measures for facilities from the first competitive solicitation (which lacked developers' estimates of economic benefits). The direct and indirect effects were calculated for the short-term and long-term economic measures.

Short-term measures were:

- Jobs lasting up to three years such as construction, planning, and engineering;
- Payments to municipalities that do not persist over the life of the facility;
- Payments to abutting landowners or others that could be affected by the facility but which are not receiving payments from hosting the facility on their land; and
- Initial equipment or one-time capital expenditures (such as turbines or repowered upgrade equipment).

Long-term measures, which are tied to the life of the facility's operations, include:

- Payroll;
- Number of jobs and their duration (described as job years)[18];
- Taxes or payments in lieu of taxes to state and municipalities;
- Fuel purchases (for biofuels);
- Land leases; and
- Other O&M in-state spending on equipment, supplies, and services.

Select jobs and earnings results are presented in Table 4. The results shown in Table 4 confirm that energy-sector jobs are well paying (the average reflects the initial presence of construction payroll as well). Note that the lesser average annual compensation per job among the indirect jobs created reflects, in part, the large role that household spending (by RE facility workers spending their wages in New York) exerts in the added economic value. Households tend to purchase goods and services from lower-wage sectors, such as retail.

[18] The reference to job years is customary when discussing employment changes over a time span. Three construction jobs that are in effect for one year are the equivalent of three job years. A single job that continues for three years also represents three job years.

Table 4. Select Jobs and Earnings Results from NYSERDA Study

	First 3 Solicitations	25% by 2013	30% by 2015
Direct Annual Jobs Created in NYS from Main Tier RPS			
Short-term Jobs	677	857	1,764
Long-term Jobs	223	279	600
Average Annual Over Facility Life Worker Compensation			
Direct Job Years	6,492	8,298	19,607
Direct Payroll	$501,788,643	$635,533,210	$1,481,422,272
Avg. Compensation per Direct Job	$77,293	$76,589	$75,556
Indirect Job Year Impact	16,184	20,230	45,201
Indirect Payroll Impact	$860,000,000	$1,070,000,000	$2,331,000,000
Avg. Compensation per Indirect Job	$53,139	$52,892	$51,570
Total Job Years	22,676	28,528	64,808

Pennsylvania (2004)

Black and Veatch analyzed the potential economic impacts of renewable energy development in Pennsylvania spurred by a RPS. These impacts include direct and indirect differences in the jobs, income, and gross state output associated with the alternative expansion plans. The model used in the study is the Regional I-O Modeling System (RIMS II model), developed and maintained by the Bureau of Economic Analysis.[19] The study developed a hypothetical least-cost portfolio of renewable energy technologies that would likely be developed to meet the RPS requirement that 10% of energy be supplied from new renewable energy by 2015. The study analyzed two scenarios: Business-as-usual (BAU) and Renewable Portfolio Standard (RPS). Wind energy and biomass were estimated to contribute more than 80% of the energy. The remainder is composed of hydro, digester gas, and landfill gas generation projects, and a small amount of solar photovoltaic generation.

To estimate the direct impact that an RPS would have on electricity costs, an economic model was constructed to measure the 20-year (2006–2025) cost of providing 10% of the electricity consumed in Pennsylvania from renewable energy sources. This involved comparing the cost of generating electricity under the RPS with the costs that would be avoided (avoided fuel, O&M costs, capacity costs) due to the RPS. In essence, these avoided costs represent the benefit or value of the RPS. Ignoring secondary costs and benefits, the avoided costs represent the maximum that consumers could pay for electricity and still be no worse off than in the BAU case. In other words, if the costs of the RPS are less than the BAU avoided costs resulting from the program, it is an indication that the RPS would have direct cost-of-power benefits to consumers as compared to a BAU case. Conversely, if the RPS costs are greater than the BAU avoided costs, it is an indication that the direct cost of the RPS does not result in direct electricity savings to consumers, although the RPS program still could be beneficial when secondary costs and benefits are considered.

[19] For additional information on RIMS, visit http://www.bea.gov/regional/rims.

The economic impacts of the RPS portfolio were compared to a "business as usual" case of building all fossil fuel resources. The results are as follows.

- The analysis revealed that over a 20-year span the RPS portfolio would cost $1.23 billion more than the BAU case on a present-value basis. Relatively speaking, this cost is minimal.
- When spread over all retail electric customers, this increase in cost would result in an increase in electric rates of only $0.036 per kilowatt hour, or about $0.29 per month, for the average residential customer.
- The RPS portfolio would result in $10.1 billion more in gross state output over 20 years than would the BAU portfolio.
- The RPS portfolio would provide a $2.8 billion advantage in earnings and generate about 85,000 more job-years over 20 years than would the BAU portfolio.
- A review of recent studies revealed that there is strong evidence for fossil-fuel price and consumption decreases as a result of renewable energy development. This analysis revealed that even a 1% reduction in fossil fuel prices would lead to a $140 million reduction in annual fossil fuel expenditures for power generation, or 50% of the RPS cost premium in 2015.

Additional results are presented in Table 5.

Table 5. Cumulative Impacts for Construction and Operation Periods, RPS Versus BAU Portfolios from Black and Veatch Study

	Output Impact	Earnings Impact	Employment Impact
RPS	$15,468,918,425	$4,736,305,108	129,439
BAU	$5,391,459,876	$1,897,570,828	44,272
Difference	$10,077,458,549	$2,838,734,280	$85,167

Texas (2005)

In 1999 Texas enacted its RPS—requiring 2,000 megawatts (MW) of new renewable energy capacity by 2009—as part of legislation that restructured the state's electricity market. By 2005, the Texas RPS had become one of the most effective and successful in the nation. The state is ahead of its annual requirement schedule with nearly 1,200 MW of new renewable energy already installed. Given the success of the existing law and the state's vast renewable energy potential, at least two proposals have been made to increase the state's standard. The Texas Renewable Energy Industries Association (TREIA) and a coalition of Texas environmental organizations are advocating for a long-term 20% by 2020 RPS, with 1% of the requirement set aside for distributed resources like solar energy and farm-based technologies.[20] The Texas Energy Planning Council (TEPC) is recommending a more modest increase of the standard to 5,000 MW by 2015 (500 MW from non-wind renewable resources), with a goal of 10,000 MW

[20] TREIA also recommended a shorter-term expansion of the current RPS to be adopted by the Texas Legislature in 2005, requiring 10,000 MW of renewable energy capacity (500 MW from distributed renewable resources) by 2015. This shorter-term goal is not analyzed in the UCS report.

by 2025. The Union of Concerned Scientists project that the TEPC proposal would yield approximately 8% renewable energy in 2025.

The Union of Concerned Scientists analyzed the costs and benefits of increasing the current Texas RPS based on the proposals made by TREIA and the TEPC, using the Energy Information Administration's (EIA) National Energy Modeling System (NEMS). Under the more likely scenario that primarily utilizes renewable energy technology cost projections from the Department of Energy's national laboratories, UCS found that both the 20% proposal and the 10,000 MW proposal would result in significant new benefits for Texas' economy and its environment (Table 6). Under the 20% proposal economic development and environmental benefits would be much greater, because this proposal stimulates more renewable energy development—a total of 17,820 MW by 2025.

Table 6. Comparison of Benefits, Texas RPS Proposals (More Likely Scenario)

	20% by 2020 RPS	10,000 MW by 2025 RPS
Consumer Benefits		
Electric Bill Savings	$4.6 billion	$5 billion
Natural Gas Bill Savings	$1 billion	$0.5 billion
Total Energy Bill Savings	$5.6 billion	$5.5 billion
Economic Benefits		
New jobs created	38,290	19,950
New capital investment	$9.4 billion	$4.7 billion
Biomass energy revenues	$542 million	$197 million
School tax revenues**	$1.1 billion	$628 million
Wind power land lease royalties	$154 million	$111 million

Note: Results are in cumulative net present value 2002$ using a seven percent real discount rate. Job results are for the year 2025.

*Biomass is called out as an impact because of its contribution to the proposed renewable portfolio mix.

**The impact on school tax revenues were analyzed as an impact of interest in this study

The Union of Concerned Scientists used the IMPLAN model and specific data on the Texas economy to estimate the macroeconomic impacts (employment, income, gross state product) of the Texas RPS. The macroeconomic analysis was completed by MRG & Associates.[21] Four main steps were performed to complete the macroeconomic analysis (these steps are presented above in the profile for Colorado in the study by UCS but are repeated here for ease of reference).

- First, total expenditures were estimated for installing, manufacturing, operating, and maintaining renewable energy technologies that are projected to be developed to meet the

[21] The analytical approach used in this analysis is similar to that used by Geller, DeCicco, and Laitner (*Energy Efficiency and Job Creation*, 1992, American Council for an Energy Efficient Economy).

Colorado renewable energy standard and for coal and natural gas power plants that would have been developed without the standard.

- Second, the expenditures were broken down and allocated to the industries that would directly supply the equipment, labor, and services for renewable and conventional energy technologies.
- Third, the detailed expenditures were multiplied by the estimated local share of equipment, labor, and services that could be supplied by Colorado businesses and matched to the appropriate sectors in the IMPLAN model to calculate the direct and indirect macroeconomic impacts in Colorado.
- Finally, the macroeconomic impacts of changes in consumer energy bills in Texas were calculated.

The Union of Concerned Scientists also adopted several key assumptions for the macroeconomic analysis. The expenditure breakdown for the construction and operation and maintenance of renewable and conventional power plants was based on data from actual projects collected from a variety of sources, including state and federal agencies, renewable energy developers, and utilities. The expenditure breakdown and local share data on wind projects—the technology that benefits most under the RPS[22]—were based on inputs used in the NREL Jobs and Economic Development Impacts (JEDI) Model.[23] Data from the IMPLAN model was used to estimate the local share of expenditures for specific industries, with a few key exceptions.

Increasing the Texas RPS to the levels analyzed in this study would create a large market for renewable energy in the state, which would help attract businesses that manufacture technologies and components and provide services. Implementation of the current standard already has resulted in an estimated 2,500 direct jobs from Texas businesses supplying wind towers; blades; and development, construction, and transportation services (The SEED Coalition and Public Citizen's Texas Office 2002). Based on this information, the analysis made the following assumptions about the share of expenditures and manufacturing that could be supplied by local businesses.

- 100% of the towers and blades for wind turbines
- 33% of other wind turbine components and solar photovoltaic panels
- 100% of solar water-heating collectors
- 100% of natural gas fuel expenditures and 52% of coal fuel expenditures (based on data from EIA) (EIA 2009b)

Also completed was a sensitivity analysis that assumed that 100% of other wind turbine components and solar photovoltaic panels are manufactured in the state. The analysis did not include any jobs or economic development from Texas manufacturers exporting equipment to other states or countries. If Texas is able to attract renewable energy manufacturers to produce equipment for facilities in the state and for export, the jobs and income from the standard would increase significantly.

[22] Considering the wind resource in Texas, in areas that have the best wind resources wind energy can compete on a lowest-cost resource basis with fossil fuels on a long-term basis.
[23] For more information about the JEDI model, see http://nrel.gov/analysis/jedi/

Washington (2006)

The Union of Concerned Scientists analyzed the costs and benefits of the renewable energy and energy efficiency provisions of Initiative 937 (I-937) in the State of Washington, which would establish a renewable energy standard requiring the state's largest electric utilities to supply 15% of their electricity sales from eligible renewable resources by 2020. Under the expected case, which primarily utilizes cost and performance projections from industry experts—the U.S. Department of Energy and the Northwest Power and Conservation Council—UCS found that, by 2025, I-937 would result in economic benefits including:

- 2.9%, or $1.13 billion, in savings on consumer electricity bills resulting mostly from reduced natural gas demand and reduced natural gas prices, resulting from the increase in renewable energy availability;
- 2,000 new jobs in manufacturing, construction, operation, maintenance, and other industries;
- $138 million in additional income and a $148 million increase in gross state product;
- $2.9 billion in new capital investment;
- $30 million in income to rural landowners from wind-power land leases; and
- $167 million in new property tax revenues or payment in lieu of taxes for local communities.[24]

This analysis uses a spreadsheet model to estimate the cost and benefits of Washington's I-937 ballot initiative. These impacts are calculated by analyzing the interaction between renewable energy and energy efficiency supply and policy-driven demand in a competitive wholesale market. The Tellus Institute and the Institute for Lifecycle Energy Analysis initially developed the modeling approach on behalf of the NW Energy Coalition for a 2003 report that examined a policy similar to I-937 (Lazarus et al. 2003). UCS updated the model to reflect current conditions in the electric power industry, and to match the provisions included in I-937. To calculate the macroeconomic impacts (employment, income, gross state product) of I-937, UCS used the Impact Analysis for Planning (IMPLAN) model, with data specific to Washington.

The intent of the analysis is to measure relative effects, not absolute effects. Many different factors influence utility-rate levels, revenue requirements, and resource costs, and UCS attempted to measure only the effects of I-937. Additionally, UCS makes the general assumption that the energy efficiency and renewable resource development that occurs after I-937 takes effect is attributable to the initiative. Therefore, UCS compares I-937 compliance with a reference case in which no further energy efficiency and renewable resource investments are made after 2009. It is not unreasonable to expect that some amount of energy efficiency and renewable resource development would take place in the absence of additional policy support. The level of development under I-937, however, would be predictable and assured for energy efficiency and for renewable energy; without I-937, the outlook is highly uncertain and hard to predict. The primary focus of the analysis is to examine the overall costs and benefits to consumers of the level of renewable energy and energy efficiency that is required by I-937.

[24] Results are in cumulative net present value 2005 dollars using a 4% real discount rate. Job results are for the year 2025.

The UCS analyzes the range of costs and benefits under an expected case that primarily utilizes renewable energy cost and performance projections based on information from industry experts—the Department of Energy's national labs that study renewable energy technologies, and the EIA—as well as data on energy efficiency and avoided cost of power generation from the NPCC's Fifth Power Plan. Additionally, UCS analyzes several sensitivities to determine the effects of I-937 on consumers under more adverse and pessimistic conditions.

Wisconsin (2003)

Using an updated version of a model developed for the University of Wisconsin and the Wisconsin Division of Energy in 2003, the Union of Concerned Scientists examined the costs and benefits of increasing Wisconsin's renewable standard to 10% by 2015. It was found that the 10% standard would provide significant economic and environmental benefits, and would help to protect consumers from rising natural gas and electricity prices.

The analysis uses a relatively simple and transparent spreadsheet model to project the costs, renewable generation mix, and carbon dioxide (CO2) emission reductions of increasing Wisconsin's renewable portfolio standard. These impacts are calculated in the model by analyzing the interaction of renewable energy supply and policy-driven demand in a competitive wholesale market. This modeling approach initially was developed under contract to the Massachusetts Division of Energy Resources (DOER) in 2000. Two key features in this modeling approach are (1) the incremental forward contract clearing market, which assumes that the renewable energy market is a market for long-term contracts that clears annually, and (2) a renewable generation premium, which builds the energy supply curve for each renewable generator based on the required premium over the commodity market value that is necessary to bring it on-line (i.e., to meet its levelized revenue requirement).

This study specifically addresses the local share issue by assuming that only 33% of the manufacturing for wind and solar technologies installed in Wisconsin is produced by businesses located in the state, and does not include any jobs or economic development that would result from Wisconsin-based manufacturers exporting equipment to other states or countries. If Wisconsin is able to attract renewable energy manufacturers that will produce equipment both for use in the state and for export, jobs and income generated by the renewable portfolio standard would increase significantly.

Economic Summary

There is a wide variety of approaches to take in evaluating the economic impact of an RPS. Analysis methodology can range from creating a spreadsheet to employing several discrete models evaluating specific impacts or even to the development of a more comprehensive, complex model. There are several questions to consider when deciding on an approach, but the following seem to be the most relevant through discussions with CPUC:

- What are the key impacts to measure?
- What type of data is available for input? (This could be a factor in cost and scope of the analysis.)

- What are the important aspects that the analysis should consider? For example:
    - Gross versus net impacts;
    - In-state (local share) versus out-of-state resources to meet RPS goals, including source of electric power and manufacturing capabilities; and
    - The allocation of renewable energy development attributed to the RPS (i.e., some renewable energy development would likely have occurred without the RPS. How much will the RPS take credit for?).

V. Health and Environmental Effects

This section first reviews literature and applications of the analysis of health and environmental effects of renewable electricity generation, and then offers an overview of the analysis of selected effects. Estimation of health and environmental effects of electricity generation has a long history and a variety of applications. Integrated Resource Planning (IRP) approaches have expanded criteria for electricity generation capacity expansion planning beyond considerations of cost and electric system performance.[25] Extensive literature about theories and methods for estimating these effects has been developed over the years to support IRP and other applications, and as a subject of basic environmental economic research on externalities.[26] Analyses that supported IRP emphasized quantification of air emission effects, although other effects sometimes were included qualitatively (EIA 1995). In Europe, the ExternE project has developed methods to quantify electric-sector externalities[27]—including environmental impacts, global warming impacts, and accidents—in great detail (ExternE 2009). Substantial related analysis and research also has occurred in the context of "co-benefits" analysis of greenhouse gas mitigation,[28] and prevention of global climate change also is an important effect. Effects of air emissions are the most well quantified, and economic valuation of effects of air pollution mitigation has well-developed methods and completed studies.

In the United States, state and regional analyses of costs and benefits of renewable generation generally have not included holistic treatment of health and environmental effects, but some do include one step towards estimating health and environmental effects of renewable electricity generation: air-emissions effects estimates. Most recent analyses have been performed as part of RPS evaluations, other renewable generation deployment efforts, or greenhouse gas mitigation

[25] Although many states moved away from IRP due to regulatory reform, analysis of environmental effects undertaken for IRP remains relevant to this discussion. A general introduction to IRP is Swisher, J.N.; Jannuzzi, G.dM.; Redlinger, R.Y. (1997). Tools and Methods for Integrated Resource Planning, United Nations Environment Programme. http://uneprisoe.org/IRPManual/IRPmanual.pdf (accessed April 23, 2009).

[26] Some of the more recent reviews include: Schleisner, L. (2000). "Comparison of Methodologies for Externality Assessment." *Energy Policy* 28:1127–1136; Sundqvist, T.; Söderholm, P. (2003). "Pricing Environmental Externalities in the Power Sector." *Ecological Economics* 46:333–350; Stirling, A. (1998). "Valuing the Environmental Impacts of Electricity Production: A Critical Review of Some 'First-Generation' Studies." *Energy Sources* 20:267–300.

[27] Externalities are societal costs not included in the monetary cost of electricity. Environmental impacts or effects include all effects, regardless of whether their costs are included.

[28] The IPCC Fourth Assessment Report, Working Group III, summarizes co-benefits, primarily those associated with air-pollution reduction, including human health, agricultural production, ecosystems, and avoided air pollution control costs. http://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4-wg3-chapter11.pdf (section 11.8) (accessed April 23, 2009). The U.S. EPA has pursued a long-term co-benefits analysis project, again primarily focused on air-pollution effects. http://www.epa.gov/ies/ (accessed April 23, 2009).

policies. Although this review identified qualitative consideration of diverse effects of RPS,[29] it seems that primarily emissions effects have been quantified.

The U.S. EPA has substantial tools, data, resources, and expertise that can support states and regions in estimating effects of renewable electricity generation. Some EPA methods to estimate air-emissions reduction effects have been developed through a series of congressionally mandated periodic studies of costs and benefits of Clean Air Act Amendments of 1990 (EPA 2009a). The EPA has developed tools for screening benefits (such as Co-Benefits Risk Assessment Model (COBRA)), and for valuing certain air emissions effects (BenMAP) (EPA 2009b). EPA had a variety of resources for states related to clean energy, and is developing a guide to evaluation of the multiple benefits of clean energy technologies, which will address the topic of this report in considerable detail (EPA 2009c).

Table 7 summarizes recent studies and methods, and identifies which of these were selected for further elaboration below. To identify relevant studies, we used personal knowledge of the DOE Clean Energy and Air Quality Integration Initiative, internet searches, targeted searches on the EPA website, LBNL 2007, and personal communication with national experts. Studies identified as potentially including environmental effects in LBNL 2007 are all included in this table (Wiser et al. 2007). This analysis focuses on selected studies that appeared to utilize methods of greatest potential interest to California.

[29] For example, following is a quote from the New York Public Service Commission findings about the RPS that notes various effects, none of which appear to be quantified except the emissions.

> In general, the proposed action will have numerous potential benefits, including reduced air emissions for nitrogen oxide (NOx), sulfur dioxide (SO2), greenhouse gases and particulates; increased energy diversity and security and economic development; opportunities for more distributed generation; and greater customer choice by virtue of expanding the mix of available options to include energy alternatives that promote a cleaner, healthier environment. It may also have potential adverse effects on land use, aquatic and terrestrial resources, community character, culturally and visually sensitive resources, and air emissions.

http://www3.dps.state.ny.us/pscweb/WebFileRoom.nsf/0/85D8CCC6A42DB86F85256F1900533518/$File/301.03e0188.RPS.pdf?OpenElement (accessed April 23, 2009).

Table 7. Summary of State Health and Environmental Analyses of RE Generation

Analysis	Produced By	Year	In Review	Reports Quantitative Air Emissions Effects	Reports Other Quantitative Health or Environmental Effects	Reviewed Below	Model	Notes
CA	CARB	2008	No	Yes	Yes	Yes	Several	Effects of Scoping Plan; RPS part of overall estimate http://www.arb.ca.gov/cc/scopingplan/document/appendix2.pdf
CA/ OR/ WA	Tellus	2004	Yes	No	No	No	NEMS	Raw NEMS results would have emissions-related data, but these were not published. http://www.ef.org/westcoastclimate/B_Tellus_Turning_Corner.pdf
CO	UCS	2004	Yes	No	No	No	NEMS	Raw NEMS results would have emissions-related data, but these were not published. http://www.ucsusa.org/assets/documents/clean_energy/co_ballot_res_report_-_final.pdf
DC/ VA/ MD/ NJ	DJ Consulting	Multiple studies	No	Yes	No	Yes (DOE)	TMM	DOE-supported project developed "time-matched marginal" method for estimating emissions avoided due to EE and RE. DC/VA/MD: Ongoing; NJ: http://www.nrel.gov/applying_technologies/pdfs/41173.pdf
IL	Shaw	Multiple studies	No	Yes	No	Yes (DOE)	Power World	DOE-supported project developed dispatch-model-based method for estimating emissions avoided due to energy efficiency and renewable energy. Initial project: http://www.erc.uic.edu/PDF/Clean_Energy_Development.pdf Follow-up project: Ongoing
IN	Peter Boerger	2006	Yes			No		Report not found
NESCAUM	NESCAUM	On-going	No	Yes	Yes	Yes	Several	Northeast States for Coordinated Air Use Management (NESCAUM) has ongoing projects with MA, MD, and NY; http://www.nescaum.org/
NY	NY DPS, NYSERDA, Grace, LaCapra	2003–2004	Yes	Yes	No	No	GE-MAPS	Emissions outputs from dispatch model: http://www.dps.state.ny.us/rps/RPS-COST-STUDY-II-Volume-A-2-27-04rev1.pdf
NY	CCAP, NY GHG Task Force	2003	Yes	Yes		No	IPM	Report not found
RGGI	ICF	2004–2007	No	Yes	No	Yes	IPM	http://www.rggi.org/about/history/modeling
RI	Tellus	2002	Yes			No	NEMS	Report not found; raw NEMS results would have emissions-related data
TX	UCS	2005	Yes	No	No	No	NEMS	Raw NEMS results would have emissions-related data, but these were not published; http://www.ucsusa.org/assets/documents/clean_energy/texas_res_report-02-05_final.pdf
TX	ESL	Multiple studies	No	Yes	No	Yes	eGRID-based	Texas legislature mandated reporting on air-emissions effects of energy efficiency and renewables
UT	Synapse	On-going	No			Yes (DOE)		Ongoing project

California

Objective

The California Air Resources Board performed an analysis of the public health and environmental effects of the Scoping Plan, as required by AB32 (CARB 2008a). The RPS was analyzed in combination with other elements of the Scoping Plan, and some results were reported separately for the RPS.

Methodology

The CARB methodology for performing the required analysis is described in Appendix H of the Scoping Plan. The analysis targets effects on air quality, water quality and supply, land resources, biological resources, and waste disposal and hazardous waste. These effects were used to examine the Scoping Plan's effect on public health due to changes in air quality. The analysis also examined how these effects might manifest themselves at a local level.

Effects were estimated through comparison of a business-as-usual scenario to a scenario in which the Scoping Plan was implemented. The sectors characterized in each scenario are transportation, electricity and natural gas, water, industry, recycling and waste management, forests, high global warming potential gases, and agriculture. The business-as-usual scenario describes anticipated changes that are expected to occur over the analysis period due to changes in population and changes in regulations and laws. The Scoping Plan Implementation scenario describes changes, relative to business-as-usual, that are expected due to the Scoping Plan.

For each of the targeted effects (air quality, water quality and supply, land resources, biological resources, waste disposal, and hazardous waste), the analysis estimates quantitative or qualitative effects attributable to Scoping Plan measures. The RPS is found to have effects on each of the targeted environmental effects; however only effects on air quality are quantified in detail. CARB emission factors are used to estimate air emissions from electricity generation (Scoping Plan, Appendix H, p. H-34). The effect of the RPS on air emissions presumably is estimated from the difference between the business-as-usual and Scoping Plan Implementation cases, multiplied by the emission factor for generator type. The method used to estimate health effects from the emissions effects was similar to an existing CARB method (CARB 2008b).

Results

The following tables, copied from Scoping Plan Appendix H (CARB 2008b), summarize the quantitative results of the air emissions and air quality–related health effects analysis. The RPS is a line item in the emissions results, but its emissions effects are combined with those of other measures in the health effects analysis, and so the exact health effects of the RPS are not quantified.

Table 8. Scoping Plan Appendix H, Table H-4

Table H-4: Estimated Statewide Co-Pollutant Emission Changes from Electricity and Natural Gas Sector Measures in Proposed Scoping Plan
(tons per day in 2020)

Measure	NOx	PM 2.5	ROG	CO	SOx
(E-1) Energy Efficiency (Electricity)	-7.0	-4.0	-1.0	-14.2	-0.6
(CR-1) Energy Efficiency (Natural Gas)	-10.4	-0.8	-0.6	-4.9	-0.1
(CR-2) Solar Hot Water	-0.3	-0.03	-0.02	-0.2	0
(E-4) Million Solar Roofs	-1.0	-0.6	-0.1	-2.0	-0.1
(E-2) Increase Combined Heat and Power (change from boiler to CHP) [a]	-2.0	+0.6	-0.7	-12.7	+0.1
(E-2) Increase Combined Heat and Power (avoided grid electricity) [a]	-6.4	-4.3	-0.9	-13.2	-0.6
(E-3) Renewables Portfolio Standard	-9.8	-5.6	-1.4	-19.9	-0.8
Electricity and Natural Gas Sector Total [b]	**-36.8**	**-14.3**	**-4.6**	**-67**	**-2.1**

[a]Combined Heat and Power emission changes were not included in the public health analysis, due to uncertainty in where they would occur.

[b]Numbers may not add up as presented due to rounding.

Table 9. Scoping Plan Appendix H, Table H-7

Table H-7: NOx and PM2.5 Statewide Reductions from Recommended Scoping Plan Measures used in Public Health Evaluation
(tons per day)

Measure	NOx	PM2.5
Light-Duty Vehicle • Pavley I and Pavley II GHG Standards • Vehicle Efficiency Measures	1.6	1.4
Goods Movement Efficiency Measures	16.9	0.6
Medium and Heavy-Duty Vehicle GHG Emission Reduction • Aerodynamic Efficiency • Hybridization	5.6	0.2
Regional Transportation-Related GHG Targets	8.7	1.4
Energy Efficiency (Electricity)	7.0	4.0
Energy Efficiency (Natural Gas)	10.4	0.8
Solar Water Heating	0.3	0.03
Million Solar Roofs	1.0	0.6
Renewables Portfolio Standard	9.8	5.6
Total	**61**	**15**

Table 10. Scoping Plan Appendix H, Table H-8

Table H-8: Estimates of Statewide Health Outcomes of Recommended Scoping Plan Measures[a]
(mean number of cases)

Health Endpoint	Health Benefits of 2007 SIP *mean*	Health Benefits of Recommended Proposed Scoping Plan Measures (Transportation and Electricity and Natural Gas Sectors) *mean*
Avoided Premature death	3,700	400
Avoided Hospital admissions for respiratory causes	770	84
Avoided Hospital admissions for cardiovascular causes	1,400	150
Avoided Asthma and lower respiratory symptoms	110,000	11,000
Avoided Acute bronchitis	8,700	910
Avoided Work loss days	620,000	67,000
Avoided Minor restricted activity days	3,600,000	380,000

[a] Uncertainty intervals for each estimated benefit range within 20-70 percent of the mean benefit (presented in this table). For example, the number of premature deaths avoided due to the scoping plan could be between 110 and680.

Land resource effects of new renewable facilities are qualitatively described, and consideration of these effects at the project level is recommended (Scoping Plan, Appendix H, p. H-52). Water effects of the Scoping Plan are not judged significant overall; Scoping Plan, Appendix H, p. H-66, considers individual generation technology water usage. Biological resource effects are noted as a siting issue for new facilities, and specific effects of renewable generation technologies are described (Scoping Plan, Appendix H, p. H-79). Waste disposal and hazardous waste effects of the Scoping Plan are not judged to be significant, and individual renewable generation technology effects on wastes are qualitatively presented (Scoping Plan, Appendix H, p. H-88).

United States Department of Energy

The Department of Energy has supported a wide variety of state projects to demonstrate air quality benefits of renewable energy and energy efficiency technologies through its Clean Energy and Air Quality Integration Initiative. This section summarizes quantitative methods that have been used or are being developed in projects in Washington, D.C.; Virginia; Maryland; New Jersey; Illinois; and Utah. Additionally, DOE support has contributed to the development of the NESCAUM and Texas analyses, which are summarized in separate sections.

Objective

The state projects reviewed here have the objective of quantifying environmental and economic effects of renewable energy and energy efficiency.

Methodology

Time-Matched Marginal (TMM)

The ongoing project in the Washington, D.C., metropolitan region and completed project to evaluate New Jersey's Clean Energy Program (NREL 2007a, NREL 2007b), both supported by DOE, used a time-matched marginal (TMM) method to estimate air emissions effects of electric-sector renewables and efficiency. This method uses historic plant-level data to estimate on an hourly basis which fossil generators are most likely to be displaced by renewable generation.[30]

Illinois

The DOE contributed to Illinois' evaluation of its Sustainable Energy Plan (NREL 2007c), and an ongoing project contributes to the state's evaluation of its Climate Action Plan. The methods for these project use electric-sector dispatch models to estimate differences in emissions between scenarios with and without the policy measures. The ongoing project is intended to produce methodology that can be applied to other states.

Utah

An ongoing DOE-supported project will develop cost/benefit metrics for Utah to quantify effects of energy efficiency and renewable energy, including changes in water use and air emissions (criteria and CO2); economic valuation of environmental effects of these changes; and health, energy security, and energy-reliability effects.

Results

TMM

Sample results from evaluation of New Jersey's Clean Energy Program are shown in Table 11, which is taken from the detailed project report (Jacobson et al. 2006). Results are reported for nitrogen oxide (NOx) because of the project goal of identifying emissions reductions that would support ozone reduction.

Table 11. New Jersey Clean Energy Program Sample Results

Table 2. Avoided NO_x Emissions

Year	Summer Electricity Savings (MWh)	Credited NO_x Rate (lb/MWh)	Credited NO_x Emissions (tons)
2005	322,999	1.50	242
2006	459,635	1.50	345
2007	613,387	1.24	380
2008	789,413	0.97	383
2009	993,723	0.92	458
2010	1,233,412	0.88	540
2011	1,516,942	0.83	631
2012	1,854,483	0.79	733

[30] For additional information about the method, please contact Debra Jacobson at djconsultingllc@earthlink.net.

Illinois
Sustainable Energy Plan evaluation results are summarized in Table 12 (NREL 2007c). The final report from this project has not been published.

Table 12. Illinois Evaluation Results

Cumulative Estimated Emissions Decrease, 2007 – 2013				
Area	SO_2 (tons)	NOx (tons)	Hg (lbs)	CO_2 (tons)
Illinois	51,020	4,909	238	16,155,650
Rest of study area	53,062	5,704	168	8,695,001
Seven State Area	51,670	7,334	354	18,821,400
Total	155,752	17,947	760	43,672,051

Utah
Results are not complete.

Northeast States for Coordinated Air Use Management

Objective

Northeast States for Coordinated Air Use Management (NESCAUM) undertakes studies with states that examine the multiple effects of efficiency and renewable energy. NESCAUM has ongoing studies with Maryland, Massachusetts, and New York that assess energy, economic, and health effects of renewable electricity at varying levels of detail. Studies in Maryland and Massachusetts include a screening-level analysis of health effects, whereas the study in New York includes a greater level of detail.

Methodology

Northeast States for Coordinated Air Use Management uses the New England Market Allocation (MARKAL) model (NESCAUM 2009) to develop reference case and policy-intervention case scenarios in the electricity sector, with different levels of renewable electricity generation. Outputs from NE MARKAL include air emissions for nitrogen oxide (NO_x), sulfur dioxide (SO_2), carbon dioxide (CO_2), and mercury (Hg). The Maryland and Massachusetts studies are primarily NE MARKAL scenario analyses, but include screening-level analysis of health benefits using the COBRA tool. The New York study will be more comprehensive, including Regional Economic Models, Inc. (REMI) economic analysis, air quality analysis, and BenMAP valuation.

Results

Results for the Maryland study were to be published by April 2009. Results for the New York study are anticipated during summer 2009.

Regional Greenhouse Gas Initiative

Objective

The primary purpose of this analysis was to assess effects of the Regional Greenhouse Gas Initiative (RGGI) program on electric-sector capacity expansion, generation, and costs. Carbon dioxide, nitrogen oxide, sulfur dioxide, and mercury emissions were estimated.

Methodology

This analysis used the Integrated Planning Model (IPM) model to produce state-level results for a wide variety of cases, including numerous reference and RGGI cases.

Results

Sample results are shown below from the October 11, 2006, RGGI package scenario (RGGI 2009).

CO2 Emissions [Million Tons]	2006	2009	2012	2015	2018	2021	2024
MA	25	23	24	25	24	24	24
CT	10	12	12	11	11	12	13
ME	1	1	2	1	1	1	1
NH	8	8	5	5	5	5	5
RI	2	1	2	1	1	1	1
VT	-	0	0	0	0	0	0
NY	53	52	51	52	53	53	55
DELMARVA	9	10	10	9	9	8	8
NJ	18	17	17	18	19	19	20
Total RGGI Emissions	125	123	123	123	124	123	126
Total Emissions at Affected Plants	121	118	118	119	120	119	122
Eastern Interconnect without RGGI Em	2,216	2,307	2,446	2,570	2,619	2,732	2,849
Total Eastern Interconnect Emissions	2,342	2,430	2,568	2,693	2,743	2,856	2,974
Total Canadian Emissions	65	66	67	72	80	89	97

NOX Emissions [Thousand Tons]	2006	2009	2012	2015	2018	2021	2024
MA	17	16	14	12	12	12	13
CT	6	5	5	3	3	3	3
ME	0	0	0	0	0	0	0
NH	6	7	4	4	4	4	4
RI	0	0	0	0	0	0	0
VT	-	0	0	0	0	0	0
NY	43	37	34	28	27	28	28
DELMARVA	13	13	12	11	10	7	7
NJ	19	9	9	10	9	10	10
Total	104	87	78	68	66	66	67

SO2 Emissions [Thousand Tons]	2006	2009	2012	2015	2018	2021	2024
MA	36	17	20	17	17	16	15
CT	10	5	6	6	6	3	3
ME	-	-	-	-	0	0	0
NH	50	6	4	4	4	4	4
RI	-	-	-	-	-	-	-
VT	-	-	-	-	-	-	-
NY	109	86	92	80	75	57	54
DELMARVA	93	69	52	53	51	16	11
NJ	70	30	19	17	13	12	12
Total	368	214	193	177	166	108	100

MER Emissions [Tons]	2006	2009	2012	2015	2018	2021	2024
MA	0.24	0.26	0.16	0.16	0.16	0.14	0.13
CT	0.18	0.14	0.09	0.09	0.09	0.09	0.09
ME	-	-	-	-	-	-	-
NH	0.13	0.03	0.03	0.03	0.03	0.03	0.03
RI	-	-	-	-	-	-	-
VT	-	-	-	-	-	-	-
NY	0.72	0.62	0.53	0.52	0.53	0.50	0.46
DELMARVA	0.22	0.14	0.08	0.07	0.06	0.05	0.03
NJ	0.39	0.11	0.10	0.10	0.08	0.08	0.07
Total	1.9	1.3	1.0	1.0	1.0	0.9	0.8

Figure 2. Sample results

Texas

Objective

The Texas legislature mandates reporting on the emissions effects of renewable electricity generation. Texas Energy Systems Laboratory has developed a reporting system that meets this requirement (ESL 2009a).

Methodology

The methodology relies upon historical dispatch of generation to identify which fossil generators are likely to be displaced by renewable electricity generation. This method was developed by the EPA based on Emissions & Generation Resource Integrated Database (eGRID) data.

Results

Results are published in a report series that is available on the Energy Systems Lab website (ESL 2009b).

Table 13. Comparison of Various Models

Model Name	Availability	Model Description	Pros and Cons
BenMAP	Available from EPA: http://www.epa.gov/air/benmap/	Calculates human health benefits of air quality changes.	Pros: Provides a simple, integrated framework for valuation of many health effects. Cons: Cannot use air emissions as inputs.
COBRA	Not generally available	Screening tool developed by EPA to estimate value of air quality changes.	Pros: Simple framework for screening benefits. Cons: Not generally available in all regions.
eGRID	Available from EPA: http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html	Comprehensive set of historical data on emissions from electric generators.	Pros: Based on actual emissions data. Includes most electric generators. Organized by major categories. Cons: Does not project future emissions or future dispatch. Only includes major air emissions. Does not include data relevant for marginal analysis.
GE MAPS	Software or consulting can be purchased from GE: http://www.gepower.com/prod_serv/products/utility_software/en/downloads/10320.pdf	Electricity market simulation software package. Includes generation, power flow, load, and transmission databases.	Pros: Supports analysis of spot prices or locational marginal prices (LMP), shadow prices, determination and evaluation of transmission congestion, environmental compliance, generation siting, asset evaluation, and revenue stream projection. Cons: Complicated model requires considerable investment to run. Includes only major air emissions.
IPM	Proprietary model owned by ICF. http://www.epa.gov/airmarkt/progsregs/epa-ipm/index.html	Linear programming model of the electric sector in the United States. Deterministically forecasts capacity expansion, dispatch, and emission control to meet constraints of energy demand, environmental compliance, transmission, dispatch, and reliability.	Pros: Primary tool used to estimate policy effects on SO_2, NO_x, CO_2, and Hg in electric power sector. Cons: Does not include sufficient geographic detail to model many issues of renewable electricity generation.

Model Name	Availability	Model Description	Pros and Cons
NE MARKAL	Developed by NESCAUM: http://www.nescaum.org/topics/modeling	Energy system model including technology-based representation of each step in the energy supply chain, from resource extraction through conversion processes to end-use devices meeting end-user demands.	Pros: Comprehensive representation of energy system. Can be linked with other MARKAL models. NESCAUM has developed analyses using MARKAL outputs with other models, such as REMI and BenMAP. Cons: Does not include sufficient geographic detail to model many issues of renewable electricity generation.
NEMS	—	See models table in economic section of this report.	—
Power World	Software or consulting can be obtained from Power World: http://www.powerworld.com/	Simulates power flow in an electrical grid.	Pros: Analysis produces electric generation that is feasible within transmission system. Cons: Complicated model requires considerable investment to run. Includes only major air emissions.
TMM	Proprietary method of RSG Consulting: http://www.rsginc.com	Estimates time-matched marginal emissions rates from electricity generation.	Pros: Can be used to estimate avoided emissions attributable to renewable generation without running a dispatch model, based on historical data. Cons: Not publicly available at this time. Not appropriate for substantially changed situations.

For pollutants subject to a cap, such as sulfur dioxide, mercury, and in some areas nitrogen oxide, an RPS is likely to reduce allowance prices but not emissions (unless an emission level is quite high). Any health effects beyond those already ensured by air quality regulations would be from non-capped pollutants. Because of caps, reported emissions reductions must be interpreted carefully. Some of the supporting documentation for the New York RPS analysis notes modeled emission reductions (New York State 2004), for example, but whether these are achieved in practice for all pollutants depends on the cap and trade regulations and associated markets. The importance of estimating actual emission changes—and not just theoretical ones achieved if renewables substituted for emitting generators—often is overlooked or ignored (IRFC 2006).[31] Thus, if air quality regulations already ensure a certain level of protection through a cap, then the value of renewable generation could be in reducing the cost of compliance with those regulations, rather than enhancing health and environmental protections.

VI. Overview of Analysis and Effects

Having briefly reviewed the related literature and applications in the United States, next is an overview of analysis and effects. Renewable electricity generation offers a different set of environmental effects relative to fossil or nuclear generation. The most significant differences are in air emissions and air quality, solid waste and hazardous materials, water resources, and land use (with associated possible effects on biological and recreational resources),[32] each of which is introduced below. Of these, air emissions differences are most likely to result in

[31] The negative effects of emissions from fossil generation, for example, often are sited as a benefit of renewable generation, without actually showing that these emissions and associated effects would be reduced under current regulatory frameworks.
[32] These categories of environmental effects are based on California Environmental Quality Act categories.

measurable changes in health outcomes in the general public. Occupational health effects also are likely to be measurably different among the different generation options.

All quantification of health and environmental effects relies upon two initial analytic design steps, which are discussed here before a consideration of specific effects.

- Step 1. Establish the overall analytic scope with respect to beginning, interim, and ending year of analysis period; spatial and temporal scale (geographic location of generation and sub-annual time slices for generation, geographic scope, and specificity; and sub-annual time slices for air quality analysis); specifications of electric generation scenarios; portions of technology life cycle; and specific health or environmental effects for analysis.
- Step 2. Estimate generation sources under each scenario in terms of type, location, capacity, and generation.

For each of these steps, estimation methods must be selected.

Step 1. Establish Scope

The following discussion presents each scoping element from step 1, with options and considerations for method selection.

Analysis Period

This already might be defined by the scope of the study. Considerations in selecting the analysis period could include availability of data sets for the initial year, analysis periods used in other related analyses, and policy-related dates. It might be desirable to extend the analysis period beyond policy-related end dates—at least for portions of the analysis—if interesting policy effects are expected to continue. For example, air quality changes at full implementation of the RPS could persist and continue to affect health outcomes thereafter.

Spatial and Temporal Scale

The spatial and temporal scale should be selected with the analytic endpoint in mind. For air-quality-related health outcomes, for example, the spatial and temporal scales used to identify electricity generation should not constrain the spatial scales that can be used in the air quality and health analysis. This means that the spatial and temporal data about electricity generation should be at least as high-resolution as the air quality modeling framework. An 8,760-hour per year generation profile by generation source with latitude and longitude is likely to be more than adequate, but if less generation data is retained it might need to be matched with requirements of the dependent analyses with respect to specific seasons or larger geographic areas.

Technology Life Cycle

Air emissions, solid and hazardous wastes, and water and land resource effects occur at other stages of the technology life cycle and not just during generation.[33] A scoping decision is needed on life-cycle stages to include. Including other life cycle stages (besides generation) could be especially important for certain technologies, therefore a reasonable option could be to include different life-cycle stages for different technologies and types of effect. Life-cycle assessments

[33] The U.S. Life Cycle Inventory Database provides data on material flows for a wide variety of basic processes and is used in performing life cycle assessments. http://www.nrel.gov/lci/ (accessed April 24, 2009).

of generation technologies including coal, natural gas, and biopower are available.[34] Additionally, the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation[35] (GREET) Model includes full fuel-cycle emissions and energy estimates. Although it is not as extensive as a full life-cycle assessment, it can be used to estimate certain upstream emissions and energy effects. If the CPUC decided to include effects of some upstream processes, GREET or related analyses could be useful.

Step 2. Estimate Generation Sources

Specifications of Electric Generation Scenarios

The overall renewable generation targets are defined in the policy (business-as-usual with 20% RPS, 33% RPS) but the exact generation sources are not set by the policy, so there could be several side cases exploring different generation mixes. Following are some examples.

- Aggressive distributed generation case that emphasizes rooftop photovoltaics (PV) (likely to reduce land use change)
- Aggressive wind case (likely to show different emissions reductions as compared to the other mixes)
- Aggressive renewable baseload case that assumes high availability of enhanced/ engineered geothermal systems, concentrating solar power, and biopower (can displace imported coal-fired baseload plants)
- Aggressive regional renewables case that assumes high penetration of renewables throughout the Western Interconnect

If it is undesirable to have a great number of side cases, displaced fossil emissions could be bounded by two cases, one with all renewables displacing peak load and one with all renewables displacing baseload. In the peak load case, adequate ancillary services should be taken into account. If renewables in the core case displace mainly peak or baseload, then a single side case could be selected that focuses on the other condition.

It is understood that a capacity expansion model was not used to estimate the generation sources. Capacity expansion modeling could be used to optimize the mix of generation sources.[36] Also understood is that, for a few selected cases (probably two), the Plexos model (Plexos Solutions 2009) will be used to develop detailed production cost and power flow results.

[34] A search on "life cycle" in the NREL publications database will yield an extensive list of life-cycle assessments of both renewable and fossil-fuel technologies. http://www.nrel.gov/publications/

[35] Argonne National Laboratory maintains GREET. http://www.transportation.anl.gov/modeling_simulation/GREET/

[36] Many of the challenges in modeling large-scale renewable energy deployment are addressed in the Regional Energy Deployment System (ReEDS) model. If further analysis of the generation mix is feasible, it could be valuable to use ReEDS.

VII. Air Quality: Air Emission, Air Quality, and Health and Environmental Effects

Air emissions changes are likely to be the single most significant quantifiable effect of electricity generation.[37] Air emissions can affect global climate, human health, and other environmental endpoints. Quantifying greenhouse gas emissions effects on global climate is probably beyond the scope of analysis—although reduced greenhouse gas emissions likely will be a significant effect of RPS and one of the core benefits that the CPUC already is analyzing. Quantifying human health and environmental effects can be undertaken through the following general steps, and quantifying other environmental effects of air emissions also could be pursued[38] (steps 1 and 2 are discussed above).

- Step 3. Estimate emissions of the selected air pollutants and their precursors under each scenario.
- Step 4. Estimate concentrations of the air pollutants under each scenario.
- Step 5. Estimate health and environmental outcomes under each scenario.

Step 3. Estimate Emissions

Electricity generation contributes to criteria and toxic air-pollution problems. The Climate Change Scoping Plan relied on the California Air Resources Board methodology for air pollution and health effects estimation (CARB 2006). For this analysis, an alternative scope and methodology could be developed or the CARB method could be used. An alternative scope could include additional pollutants, although it is understood that this is unlikely. Following is a brief discussion of pollutants.

Particulate matter and ozone are the criteria pollutants with the greatest health effects in California. Particulate matter was analyzed in the Climate Change Scoping Plan, and is likely to have the greatest health effect.[39] One alternative is to extend the scope to ozone or, if ozone is not included, a simplifying assumption could be considered that the effect of ozone is unlikely to exceed that of PM. However, the validity of such an assumption would require further evaluation. Another possible direction in which to extend the scope is to include toxic air pollution (and related water and hazardous waste issues).

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[37] U.S. EPA's 2003–2008 Strategic Plan is the most recent for which societal costs and benefits were summarized for different environmental goals. Monetized benefits of air quality programs are significantly greater than those that can be monetized for other environmental media. This summary provides a good overview of which environmental effects can be most readily quantified and which cannot. http://www.epa.gov/ocfo/plan/2003sp.pdf (accessed April 24, 2009).

[38] ExternE includes an excellent general overview of the assessment of impact pathways.

[39] A CARB fact sheet on particulate matter and ozone highlights the likely greater health impact from fine particulate matter, relative to ozone, in California, and this relative ranking probably is the same nationally. http://www.arb.ca.gov/msprog/ordiesel/documents/pm_03fs.pdf.

For example, mercury or other heavy metals could be considered for analysis. Quantification of effects of air toxics poses significantly greater analytic challenges than for particulate matter or ozone (IEI 2003).[40,41]

If particulate matter is selected for analysis, then emissions of both primary particulate matter (by size class PM2.5 and PM10) and particulate matter precursors (sulfur and nitrogen oxides) ideally would be estimated for each generation source. If ozone also is selected, then emissions estimates for its precursors—nitrogen oxide and volatile organic compounds (or reactive organic gases)—would be most important.[42]

For the selected emissions, an emission factor is needed for each generation source, control technology type, and life-cycle stage. We recommend using emission factors from CARB or EPA, where available.[43] If other life-cycle stages besides generation are included, then some emission factors from other sources might be required.[44] Future emission factors should incorporate available data on new generators or for old generators with new control technologies installed in future years. If CARB has emission factors for future years that it uses for long-term planning, these could be incorporated. If not, then future emission factors in IPM could be used. Another source is the five regional planning organizations (RPOs) across the United States that are tasked with evaluating and compiling air quality emissions data to address haze and related issues (EPA 2009d). The Western Regional Air Partnership (WRAP) compiles such data for the western United States, including California. WRAP provides annual emission estimates for point sources in its region for 2002 and 2018 that include anticipated growth and control technologies (WRAP 2009). Temporal allocation of these emissions can be done using standard EPA weighting factors or regional- or plant-specific data, if available (EPA 2009e).

If the desired emission factors already are used in the capacity expansion model, or if plant-specific emission factors are used in the Plexos model, then emissions estimates could be included in these model results. If the Plexos model has detailed, plant-specific factors that take into account load, start-up and shut-down emissions, and specific control technology, then these could be more accurate. If emissions results from these models do not use the desired emissions factors, then generation estimated from these model results (by generator type, control technology type, location, and time period) can be multiplied by emission factors. In either case, the desired result is emissions by generator type (coal, gas, bio), perhaps by control technology type, location (lat/long or region), time period (hour or aggregate), and chemical species (primary PM, NOx, SO2). Including control technology types gives a better idea of how much

[40] This table identifies quantification of air toxics as a major limitation of the first prospective analysis, which was a comprehensive estimate of benefits and costs, and explains that the second prospective analysis focuses on a case study quantifying effects of benzene as an initial step towards addressing air toxics. The analytic plan discusses emissions and ecological estimates of mercury, but it appears that health effects will not be estimated.

[41] EPA takes a risk-based approach to air toxics that seeks to direct resources towards the greatest risks. If air toxics were to be addressed, similar approaches could be used to focus on the most significant pollutants and pathways to health and environmental effects. We mention mercury because it would be a likely pollutant of concern in the electric sector, but if air toxics are included then a systematic screening is recommended. A general EPA fact sheet on air toxics risk is found at http://www.epa.gov/ttn/atw/3_90_022.html (accessed April 24, 2009). California's list of air toxics is found at http://www.oehha.ca.gov/air/allrels.html (accessed April 24, 2009). Of those listed, a select few are of particular concern in electricity generation. http://www.arb.ca.gov/energy/powerpl/guidocfi.pdf (p. 54) (accessed April 24, 2009); ftp://ftp.arb.ca.gov/carbis/research/hs2002/Nazaroff/Nazaroff1.pdf (p. 8) (accessed April 24, 2009).

[42] Good background information on criteria air pollutants is available at http://www.epa.gov/air/urbanair/

[43] EPA's comprehensive electronic emissions factor database is http://www.epa.gov/ttn/chief/software/fire/

[44] U.S. Life Cycle Inventory Database, http://www.nrel.gov/lci/

generation might have other opportunities for emissions control. To estimate upstream effects, capacity by type from the capacity-expansion model would be needed. All these results would ideally be indexed by year as well, because emission factors most likely will change over time.

Step 4. Estimate Concentrations

To estimate health impacts, ambient emissions must be converted to atmospheric concentrations. To accurately estimate particulate matter (PM) and ozone (O_3) concentrations, a photochemical air quality model must be applied to the region of interest, combining available data on emissions and meteorological conditions. These models can estimate the concentrations of primary pollutants that are emitted directly into—and transported in—the atmosphere, as well as secondary pollutants which are formed in the atmosphere from precursor emissions. Particulate matter can be emitted directly or can be formed in the atmosphere from sulfur dioxide and nitrogen oxides. Secondary PM is the greatest component of PM that is less than 2.5 microns in diameter (PM2.5). This contributes more significantly to adverse human health impacts than does PM10, or PM that is less than 10 microns in diameter.

Ozone pollution is not emitted directly into the atmosphere, but instead is formed from photochemical reactions between nitrogen oxides and volatile organic compounds (VOCs). Use of photochemical models to estimate both transport and transformation in the atmosphere ensures that ambient concentration estimates include both primary and secondary pollutants for better approximation of associated health impacts. The CARB method describes air quality modeling performed for the scoping study. NREL recommends using CARB methods for air quality modeling. For ecological effects of air emissions, deposition of pollutants on the land or water might need to be estimated. If the CPUC wishes to analyze these effects, we recommend using CARB or EPA methods.

Step 5. Estimate Health and Environmental Outcomes

A variety of health effects of air pollutants has been identified—ranging from premature death to restricted activity days—and a scoping decision could select which ones to include. The CARB method used in the Climate Change Proposed Scoping Plan (CARB 2008) specified certain health outcomes, and a reasonable option would be to select the same health effects. Additional research that might suggest adding new health outcomes could be evaluated further, especially if there are any differences between what CARB has chosen and the EPA Second Prospective study of costs and benefits of the Clean Air Act Amendments of 1990 (IEI 2003).

Health effects typically are estimated using a concentration-response (C-R) function, which quantifies the change in health outcome to be expected per unit change in pollutant concentration, and the baseline incidence of health effects. Each pollutant will have a different C-R function, and different studies or aggregations of studies imply different functions based on geography and demography. The function chosen should reflect the underlying population exposed to the atmospheric concentrations determined through air quality modeling. There seems to be no compelling reason to pursue changes in the CARB method from the scoping study, but we recommend that this study conform to the current practice of CARB or EPA. Selection of appropriate C-R functions is subject to considerable scientific discussion in the EPA analytic plan for the Second Prospective Study, because selection of different C-R functions significantly changes health-effects results.

EPA has identified ecological effects of air pollutants that are most quantifiable. These include acidification of lakes and streams, eutrophication caused by excessive nitrogen, mercury contamination, and direct toxic effects of ozone on plants (EPA 2007). Quantification methods are less well-defined for ecological effects than for health effects, and economic valuations are much less, but quantification nonetheless could be of interest to the CPUC.[45]

Solid Waste / Hazards and Hazardous Materials

In addition to the air quality and health effects introduced above, there are likely to be significant differences between renewable generation and other generation sources in the areas of solid waste and hazardous materials. Solid and hazardous wastes for most renewable technologies are produced outside the generation stage of the life cycle; in contrast, for other technologies they are produced during all life cycle stages. Therefore the scoping question related to life cycle is especially relevant to these wastes. Health and environmental outcomes associated with solid and hazardous waste are extremely diverse. If the CPUC wishes to pursue these, we recommend further consideration by other experts and use of a risk-based approach.[46] After the two initial steps, the following steps could be pursued for solid and hazardous wastes:

- Step 3. Estimate quantities of each type of solid and hazardous waste produced under each scenario.
- Step 4. Estimate resulting concentrations of hazardous substances in the environment.
- Step 5. Estimate health or environmental outcomes attributed to the solid and hazardous waste.

Within the solid and hazardous waste category, three specific waste types to consider for inclusion are coal wastes, nuclear wastes, and certain photovoltaic wastes.

Coal Wastes

The coal generation life cycle produces a variety of solid and hazardous wastes, including during mining and combustion. Many of these environmental effects could occur outside of California because of the limits on in-state coal combustion. California, however, relies on substantial quantities of out-of-state coal generation. The CPUC has indicated an interest in considering the inclusion of out-of-state environmental issues, and coal wastes could be included. Life-cycle assessments of coal, GREET estimates, as well as pollutant-specific analyses (e.g. EPA's work on mercury) (EPA 2009f) would provide good sources for such analysis.

Nuclear Wastes

Similar to coal generation, nuclear generation produces solid and hazardous wastes during several stages of its life cycle, with many—but not all—of the effects likely to occur out of state because the fuel life cycle is not confined to California. Some of these issues could be less amenable to quantitative analysis by the CPUC, however, because they depend upon resolution of major national political issues such as development of a permanent nuclear-waste repository, or they depend on risk valuation where little consensus exists (for example, "Are low-

[45] A study that used the ExternE methodology in Germany, for example, found external costs associated with global warming and health effects were about an order of magnitude greater than ecosystem costs (Friedrich, & Bickel 2001).
[46] U.S. EPA's 2003–2008 Strategic Plan includes quantitative and qualitative health and environmental effects of solid and hazardous waste. This summary could be a good starting point. http://www.epa.gov/ocfo/plan/2003sp.pdf

probability, high-consequence risks of nuclear socially acceptable?"), or depend on success of new generations of nuclear technology. We understand that new nuclear capacity is not likely to be part of any of the scenarios analyzed. In time, however, pursuit of a higher RPS might reduce or postpone installation of new nuclear capacity. If the CPUC wishes to include nuclear waste within its analysis, we recommend further evaluation of nuclear issues be conducted by other experts, with consideration that nuclear-waste effects might best be addressed qualitatively.

Photovoltaic Wastes

Certain photovoltaic materials contain toxic metals and others require use of hazardous gases during manufacturing, which can generate occupational hazards or hazardous wastes. Although hazardous materials in finished photovoltaic systems do not pose a significant risk to installers or the general public, ultimate disposal or reuse of these systems also could raise solid and hazardous waste issues (TSES 2008).[47] The CPUC will need to decide whether to include these issues in its analysis.

Water Resources

Renewable generation has different water-resource effects than those of fossil and nuclear generation. Photovoltaic and wind generation do not use water during the generation stage of the life cycle, except for nominal amounts in cleaning. Concentrating solar thermal power, geothermal, and biopower can use cooling water although water-minimizing cooling systems are envisioned—especially for CSP, which is very likely to be located in desert environments. Water-minimizing cooling systems could increase costs, therefore including this as the basic technology characteristic would be important, particularly for CSP.[48] Hydropower and ocean current generation use moving water directly, and hydropower of course requires dams which alter water flows.

Life-cycle assessments are a source of information about water usage for the technology configuration specified, although they do not always analyze different technology alternatives that could reduce water usage. California's assessment of water effects for the Scoping Plan refers to the California Energy Commission's 2007 Environmental Performance Report of California's Electrical Generation System (CEC 2008). The summary table on cooling water from that report is shown below (Table 14). The report also notes the poor quality of existing water data, and indicates that regulatory changes allow CEC to begin collecting better data for 2009. NREL has reviewed data regarding water usage in electricity generation and found it to be insufficiently detailed with regard to water-usage categories, unclear or inconsistent regarding definitions of water use and water-quality data, and inconsistent regarding data collected for different technology types.

Additionally, water usage that diverts liquid water to the atmosphere—thermal effects of water usage—are important. Renewable generation is less likely to rely on cooling water than is fossil generation, therefore its increased penetration under an aggressive RPS might reduce thermal pollution. Although renewable generators that do use cooling water and discharge it to a river or stream (most likely geothermal or biopower) might face the thermal pollution issue, each

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[47] Also see a draft of another document at http://www.nrel.gov/pv/thin_film/docs/summary_esh_from_bnl_all_techs_draft.doc. Accessed April 23, 2009.

[48] NREL's Solar Advisor Model can be used to estimate CSP costs with hybrid or dry cooling. NREL uses these estimates in its ReEDS model.

renewable plant is unlikely to be as large as a single nuclear or coal-fired facility, which reduces the local impact. Furthermore, these renewable generation technologies are unlikely to be located on the coast, and therefore would not use once-through cooling with seawater. Quantitative estimates could be made of relative cooling and other water usage of different generation technologies. Agricultural wastes can be used to generate electricity through anaerobic digestion, possibly reducing the water-quality effects of conventional waste-management practices. The CPUC will have to determine which water issues to consider in the analysis, and how to quantify these effects.

Table 14. California Energy Commission's 2007 Environmental Performance Report of California's Electrical Generation System, Summary Table on Cooling Water

Table 9: Typical Cooling Water Withdrawal and Consumption Rates for Operating Power Plants in California

Energy Resource, Plant Type, & Cooling System	Water Withdrawn for Cooling & Processes (gallons/MWhr)[1]	Water Consumed for Cooling & Processes (gallons/MWhr)	Assumed Capacity Factor	Annual Water Consumption for a 500 MW Plant[2]			
				Gallons per Year		Acre-Feet per Year	
				Min	Max	Min	Max
Steam-Cycle (with steam boilers)							
Natural Gas - Once-Through Cooling	10,000 - 60,000	95 - 285		166 million	499 million	510	1,530
Natural Gas - Re-circulating Tower	950 - 1,460	760 - 1,170	40%	1,332 million	2,050 million	4,090	6,290
Combined-Cycle							
Natural Gas - Re-circulating Tower	840 - 1,725	676 - 1,380[5]		1,156 million	2,420 million[5]	3,500	74,005
Natural Gas - Air-Cooled	60 – 225	50 - 180	40%	88 million	315 million	270	970
Simple-Cycle (peaking plants)							
Natural Gas with Inlet Cooling	100 – 750	80 - 600	20%	70 million	526 million	215	1,610
Renewable Technologies							
Solar Thermal							
Parabolic Trough	1,150 - 1,340	960 - 1,120		1,260 million	1,470 million	3,870	4,500
Solar Tower	---	---		---	---	---	---
Sterling System	5 – 7	4 - 6	30%	7 million	10 million	20	30
Geothermal	10 – 40	8 - 30	70%	25 million	92 million	75	282
Waste Energy – Biomass							
Steam - Re-circulating Tower	950 - 1,460	760 - 1,170	40%	1,332 million	2,050 million	4,090	6,290
Waste Energy – Landfills							
Simple-Cycle	100 - 1,040	80 - 830		140 million	1,454 million	430	4,460
Reciprocating Engine	0 – 1	0 - 1	40%	0	1.8 million	0	5

Notes:

1. Water withdrawal estimated as 20 percent more than the water consumed in order to account for the wastewater stream.
2. Estimated by the Energy Commission staff.
3. Water use rates do not distinguish between power plants that reuse wastewater such as from a zero liquid discharge (ZLD) systems from those that do not; ZLD can achieve approximately 15 percent reduction in the water consumed by a power plant.
4. Water use rates are based on data reported to the Energy Commission by power plant operators in 2005 as measured during calendar year 2003.
5. The upper limit of the range for water use of the combined cycle is higher than a steam turbine plant, both configured with re-circulating cooling towers, because the upper limit data for the combined-cycle plant is attributable to a warmer desert climate requiring more water for cooling.

Sources: Hewett 2003, Department of Energy 2004, with California-specific modifications by Energy Commission staff based on 2005 environmental survey data and Energy Commission siting cases.

Land Use

Generation technologies differ substantially in the quantity and type of land use required. Land use per megawatt by generation type and land-use type is feasible to quantify (Denholm and Margolis 2008). The compatibility of renewable generation with other simultaneous uses, however, is not always well understood. For example, technologies such as wind do not require exclusion of plants and animals from the entire site, but the effect on the quality of habitat for animal and plant species in an area, the cumulative effect, and the mitigation options are not well characterized. The U.S. Department of the Interior, Bureau of Land Management (BLM) has completed a Programmatic Environmental Impact Statement for wind generation (U.S. Department of the Interior BLM 2005), and the BLM is completing one for solar (PEIS 2009) and geothermal. These documents include substantial information about renewable energy environmental impacts, especially effects on land resources.

Health and Environmental Effects Summary

Scoping questions to analyze health and environmental effects of an RPS include determination of the analytic period, spatial and temporal scale, technology life cycle, and electric generation scenarios. The scope with regard to environmental releases (for example, air emissions) and their effects (for example, specific health effects attributable to human exposure to ambient air) must also be selected. The type, cost, and quality of methods will depend upon the scope and may also influence scoping decisions. We recommend careful attention at the scoping stage to the ultimate questions that the analysis is intended to answer. Table 15 summarizes questions that could be answered with additional electricity scenario and air quality analyses.

Table 15. Additional Analysis Questions

Adding *This* to Analytic Scope . . .	**Makes it Possible to Answer *This* . . .**
RPS-only analysis (versus scoping study that included RPS along with other measures)	Is RPS more or less effective at improving air quality and health, as compared to other Scoping Plan measures?
Different levels of RPS	How do effects change at different RPS levels? Is there a different RPS level that appears more optimal or more cost-effective from a health perspective?
Electric generation side cases	What are the air quality and health effects associated with specific types of renewable generation? How different are air quality and health effects likely to be if the actual renewable generation installed differs significantly from expected generation shares?
Secondary PM, ozone, other additional pollutants	What are the (new pollutant–related) air quality and health effects of the RPS?

VIII. Conclusions and Recommendations

CPUC requested technical assistance to understand the overall effects of renewable electricity generation, alternatives to quantify these effects, and considerations for determining an analytic approach. This report documents technical assistance that NREL provided in response to this request, especially with regard to economic effects, price hedging, and health and environmental effects. Conclusions and recommendations from this process include:

1. Economic, health, and environmental effects span a very broad range of specific effects, and these may vary substantially. Although it may be clear in some cases which effects are likely to be important, there may be other important effects that are not readily apparent. Therefore, careful thought is needed to scope studies of the effects so that the study design will not exclude consideration of important effects.

2. Prior analyses have been conducted in a number of states that provide references and experiences to inform California's situation. Some common methods and practices can be seen across these efforts, but no single approach or set of methods and tools predominates. Additional, more detailed, and better organized reporting of state-level analyses could facilitate learning from experience.

3. Methods to analyze economic, health, and environmental effects vary widely in cost and quality, and are in many cases limited by availability of data. A concerted effort to advance the state-of-the-art of methodology for states could improve these analyses and provide better information for state decision-makers.

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14. ABSTRACT *(Maximum 200 Words)*
The California Public Utilities Commission (CPUC) requested assistance in identifying methodological alternatives for quantifying the benefits of renewable electricity. The context is the CPUC's analysis of a 33% renewable portfolio standard (RPS) in California—one element of California's Climate Change Scoping Plan. The information would be used to support development of an analytic plan to augment the cost analysis of this RPS (which recently was completed). NREL has responded to this request by developing a high-level survey of renewable electricity effects, quantification alternatives, and considerations for selection of analytic methods. This report addresses economic effects and health and environmental effects, and provides an overview of related analytic tools. Economic effects include jobs, earnings, gross state product, and electricity rate and fuel price hedging. Health and environmental effects include air quality and related public-health effects, solid and hazardous wastes, and effects on water resources.

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NREL; renewable energy; RE; California Public Utilities Commission; CPUC; economic benefits; health benefits; environmental benefits; renewable portfolio standard; RPS; renewable electricity; Gail Mosey; Laura Vimmerstedt

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