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Putting renewables and energy efficiency to work: How many jobs can the clean energy industry generate in the US?

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ABSTRACT

An analytical job creation model for the US power sector from 2009 to 2030 is presented. The model synthesizes data from 15 job studies covering renewable energy (RE), energy efficiency (EE), carbon capture and storage (CCS) and nuclear power. The paper employs a consistent methodology of normalizing job data to average employment per unit energy produced over plant lifetime. Job losses in the coal and natural gas industry are modeled to project net employment impacts. Benefits and drawbacks of the methodology are assessed and the resulting model is used for job projections under various renewable portfolio standards (RPS), EE, and low carbon energy scenarios We find that all non-fossil fuel technologies (renewable energy, EE, low carbon) create more jobs per unit energy than coal and natural gas. Aggressive EE measures combined with a 30% RPS target in 2030 can generate over 4 million full-time-equivalent job-years by 2030 while increasing nuclear power to 25% and CCS to 10% of overall generation in 2030 can yield an additional 500,000 job-years.

1. Introduction

The clean energy industry has been targeted as a key area for investment for both environmental and economic reasons. Building up a domestically produced clean energy supply can provide greater energy independence and security, has notable environmental benefits due to reduced CO_2 emissions, and can act as a driver for significant, positive economic growth through continual innovation. Job creation is an especially pressing issue as the world recovers from the most severe recession in decades with double digit unemployment rates in many countries. Clean energy can create many domestic jobs, and additionally, many of these jobs are guaranteed to stay domestic as they involve construction and installation. By investing in energy efficiency measures, money otherwise spent on energy costs can be redirected to stimulate the economy through job creation. A wide portfolio of energy sources including low carbon approaches, such as nuclear and carbon capture, are gaining attention as there are global efforts being made to reduce carbon emission in the next two decades. In the process, through replacing outdated infrastructure and developing better energy conservation and production practices, a foundation is built for future domestic stability and growth.

An increasing number of studies are finding that greater use of renewable energy (RE) systems and energy efficiency provides economic benefits through job creation, while at the same time protecting the economy from political and economic risks associated with over-reliance on a limited suite of energy technologies and fuels. We focus on the power sector in this study as it is the largest primary energy sector and also the fastest growing sector, and most job creation studies have been done in this area.

This report reviews 15 recent studies on the job creation potential of renewable energy, energy efficiency, and low carbon sources such as carbon capture and sequestration (CCS) and nuclear power. The paper first clarifies job definitions and then a common metric and normalization methodology is introduced to allow for meaningful comparison of studies. A meta-study of many papers is done to take ranges and averages of normalized job multipliers. Unlike most other renewable energy studies, an attempt is made to take into account job losses in the coal and natural gas industry as a first step to capturing wider economy effects. Using the normalized direct employment multipliers from the meta-study, a simple analytical jobs model is described that generates job projections out to 2030 as a function of user-defined scenarios for EE, RE, and low carbon supply sources. The paper is thus a unique synthesis of many existing studies and the resultant jobs model can assist policy makers in answering three key questions:

1. What are the job creation sensitivities of adopting various clean energy approaches and energy efficiency?
2. How would large-scale growth in the renewable energy sector impact affect overall employment taking into account job losses in the fossil fuel sector?

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3. What is the job creation potential for low carbon approaches such as nuclear power or carbon capture and storage?

In order to compare the various studies on an equal footing, we adopt two simple normalizations to calculate lifetime average employment per unit of energy. First, "one-time" employment factors such as construction and installation ("job-years per peak MW") are averaged over plant lifetime to obtain an average employment number ("jobs per peak MW") that can be directly added to ongoing employment factors such as operations and maintenance. Next, to allow for comparison between technologies with different capacity factors, we calculate employment per unit of energy ("job-years per GWh") or per unit of average-MW of power output ("job-years per average MW").

Our modeling approach yields the following key conclusions:

(1) The renewable energy and low carbon sectors generate more jobs per unit of energy delivered than the fossil fuel-based sector.
(2) Among the common RPS technologies, solar photo voltaics (PV) creates the most jobs per unit of electricity output.
(3) Energy efficiency and renewable energy can contribute to much lower CO_2 emissions and significant job creation. Cutting the annual rate of increase in electricity generation in half and targeting a 30% RPS in 2030 each generates about 2 million job-years through 2030.
(4) A combination of renewable energy, EE, and low carbon approaches such as nuclear and CCS can yield over 4 million job-years through 2030 with over 50% of the electricity supply from non-fossil supply sources.

The spreadsheet-based model is available for download at http://rael.berkeley.edu/node/20.

As policy makers struggle with the current global recession and search for sectors in the economy that can provide sustainable long-term growth, these results can serve as useful data points in assessing the employment potential of clean energy and low carbon sources

2. Background

There has been a large increase in reports and interest on green jobs in the past 2 years. "Green jobs" typically refer to those jobs that play a direct role in reducing environmental impact of enterprises and economic sectors, ultimately to levels that are sustainable (UNEP, 2008). In the energy efficiency (EE) context where the majority of jobs are induced jobs from energy savings, the jobs created are not strictly "green jobs", but rather are employment opportunities that presumably would not have been created without the EE programs. In this work, we focus on job creation associated with well-defined industries or technologies including jobs in renewable energy and low carbon sources, as well as jobs resulting from energy efficiency investments.

The bulk of these reports are from non-government organizations (NGO), national laboratories, or universities but there have been fewer peer-reviewed journal publications. Multiple recent studies have appeared in the past few years on EE, wind, solar PV, solar thermal, and geothermal, while other areas have received less attention. The studies have a wide range of estimates and report their data in different ways and using different definitions of employment. All of the studies referred to in this report are from developed world.

For renewable energy, most reports are analytical-based studies. Wind is representative of this sector, and of the five studies summarized here, one is from industry, two from NGOs, one from a research institute, and one from a consulting firm. All five are essentially "bottom up" estimates based on industry/utility surveys, the outlook of project developers and equipment manufacturers, and/or primary employment data from companies across manufacturing, construction, install, and operations and maintenance (O&M). Four of five studies include direct employment estimates, only one has both direct and indirect employment estimates, while none include induced employment. Only one study includes a detailed cost benefit study.

In general, these studies comprehend the employment within a given industry such as biomass or solar. Thus net job impacts to the overall economy are not comprehended since industry to industry interactions are not captured. EE studies, on the other hand, generally utilize more complete input/output (I/O) models (Laitner and McKinney, 2008; Roland-Holst, 2008) which attempt to model full impacts to the US economy. Differences between analytical and I/O models and their relative merits are discussed further in Section 3.

As studies about green jobs have proliferated in the past few years from a wide variety of sources with varying estimates of job creation benefits and methodologies, several critiques of green jobs studies and their conclusions have appeared (see for example, Calzada, 2009; Moriss, 2009).

Critics of green job studies cite allegedly incomplete accounting for the costs of green job programs, namely the jobs that are lost or shifted by such programs, and whether large capital investments by the government would be better spent elsewhere in the private sector. For example, requiring renewable energy sources that are more expensive than conventional sources and/or directing large government subsidies for their production may drive up costs and cost jobs or may furthermore crowd out other business investment.

However, neither green job studies nor their critiques typically include avoided environmental costs or other potential benefits (less imported fossil fuel, reduced health care costs, etc.) that would favor green job programs. Longer-term costs are difficult to quantify with uncertainties in their magnitude, attribution and timing but have the prospect for catastrophic irremediable damages. Furthermore, in some cases, businesses may not be equipped or organized to invest in large-scale beneficial projects such as grid modernization where the government may need to play an active planning and/or investment role.

At the macroeconomic level, it has been argued that global warming is one of history's greatest market failures and that to preclude the prospect of severe economic and social consequences in the future a transition to a low carbon economy is urgently needed. Policies and programs to support this transition are one way of viewing the green jobs movement, and thus the key questions do not focus on whether or not to support "green jobs", but how best to do it—which policies have the greatest benefit to cost ratio, how long-term benefits should be balanced against short-term costs, how economic dislocations should be minimized, and how best to position government policies in dynamic and competitive global markets.

3. Job definitions and job study methodologies

It is important to define employment terms as there is often confusion about types of jobs and job-years. One job-year (or equivalently person-year or "full-time equivalent" FTE job) is full time employment for one person for a duration of 1 year. Often, "jobs" and "job-years" are used interchangeably; however, referring to "jobs" created without a duration can be misleading. The definitions of *direct*, *indirect*, and *induced* jobs vary widely by study. Here we describe our definitions and usage of these categories. *Direct employment* includes those jobs created in the design, manufacturing, delivery, construction/installation, project management and operation and maintenance of the different components of the technology, or power plant, under consideration. This data can be collected directly from existing facilities and manufacturers in the respective phases of operation. *Indirect employment* refers to the "supplier effect" of upstream and downstream suppliers. For example, the task of installing wind turbines is a direct job, whereas manufacturing the steel that is used to build the wind turbine is an indirect job. *Induced employment* accounts for the expenditure-induced effects in the general economy due to the economic activity and spending of direct and indirect employees, e.g. non-industry jobs created such as teachers, grocery store clerks, and postal workers. When discussing energy efficiency, a large portion of the induced jobs are the jobs created by the household savings due to the energy efficiency measures.

There are two types of studies encountered while focusing on the employment impacts in the renewable industry: (1) those that use input–output models of the economy ("top-down"); and (2) those that use simpler, largely spreadsheet-based analytical models ("bottom-up"). Both types of models have advantages and disadvantages (Kammen, 2004) and are reviewed briefly here.

I/O models are intended to model the entire economy as an interaction of goods and services between various industrial sectors and consumers. I/O models provide the most complete picture of the economy as a whole. They capture employment multiplier effects, as well as the macroeconomic impacts of shifts between sectors; that is to say, they account for losses in one sector (e.g. coal mining) created by the growth of another sector (e.g. the wind energy industry).

I/O models are thus designed to encompass both the direct and indirect employment effect of shifts in energy demand as brought upon by various policies as well as the induced economic effects due to economic impacts of spending by workers. In practice, I/O models are very complex and can be opaque to understand. Within a larger I/O model there are also disaggregation problems in modeling the employment generated by specific technology types such as solar PV or wind and in isolating the impact of specific policies versus a suite of policies. Collecting data to build an I/O model is highly data and labor intensive, and I/O models also can suffer from time delays between when industry data has been collected and when the I/O model has been run.

Most analytical models calculate direct employment impacts only, but an increasing number include indirect jobs as well. Although analytical models typically do not account for job losses in the fossil fuel sector they are much easier to understand and model. Sensitivity analysis of specific policies or changing key assumptions can be readily modeled, and data can be collected more frequently than with I/O models.

We note that quantifying job impacts in developing nations for emerging "green" industries can be a challenge for both I/O and analytical models. Consider the challenge of quantifying job impact in the recycling industry in China or India. An I/O approach would have to synthesize the employment impact by assigning some component of input supplies and labor from existing industrial sectors, while a direct approach would have quantify the job impacts of an often informal work environment. Moreover, both model types generally do not capture industry innovation which may lead to reduced job dividend over time and of course, any model is subject to policy uncertainty e.g. changes in standards, mandates, incentives, tax credits, etc.

Various normalization approaches for comparing the job creation potential of different technologies can be utilized. They include jobs produced for a given level of spending (Pollin, 2008), or jobs produced for a given level of output such as jobs produced per unit of energy production. Jobs produced per unit energy provides an indication of job creation potential for aggressive conversion of the existing energy supply to renewable and low carbon sources, and this metric is adopted here.

4. Comparing the studies

Table 1 contains a list of the studies reviewed while a detailed summary of the studies' respective methodologies is provided in

Table 1
List of studies reviewed.

Ref.	Year	Author—affiliation	Study—type of model
1	2009	Isabel Blanco and Christian Kjaer—European Wind Energy Association (EWEA)	Wind at Work: Wind energy and job creation in the EU (analytical model)
2	2009	Julio Friedmann—Lawrence Livermore National Laboratory	Personal communcation, 13 February 2009, on Carbon capture and storage job impacts (analytical model)
3	2009	José Goldemberg—State of São Paulo, Brazil	Personal communication, 13 February 2009, on Energy efficiency and jobs data
4	2009	SkyFuels and National Renewable Energy Laboratory	Personal communication, 21 March 2009, on Solar Thermal jobs data. (I/O model)
5	2008	John A. "Skip" Laitner and Vanessa McKinney—American Council for an Energy Efficient Economy	Positive Returns: State Energy Efficiency Analyses Can Inform US Energy Policy Assessments (I/O model)
6	2006	Winfried Hoffman, Sven Teske—European Photovoltaic Industry Association (EPIA) and Greenpeace	Solar Generation: Solar Electricity for Over One Billion People and Two Million Jobs by 2020 (analytical model)
7	2006	McKinsey Consulting	Wind, Oil and Gas: the Potential of Wind (analytical model)
8	2006	George Sterzinger—Renewable Energy Policy Project (REPP)	Jobs and Renewable Energy Project (analytical model)
9	2006	L. Stoddard, J. Abiecunas, R. O'Connell—National Renewable Energy Laboratory	Economic, Energy, and Environmental Benefits of Concentrating Solar Power in California (I/O model)
10	2005	Doug Arent, John Tschirhart, Dick Watson—Western Governors' Association	Clean and Diversified Energy Initiative (CDEAC) Geothermal Task Force (analytical model)
11	2004	Daniel M. Kammen, Kamal Kapadia, and Matthias Fripp—Energy and Resources Group, Universtiy of California, Berkeley	Putting Renewables to Work: How Many Jobs Can the Clean Energy Industry Generate? (analytical model)
12	2004	C.R. Kenley, et al.—Idaho National Engineering and Environmental Laboratory (INEEL) and Bechtel BWXT Idaho, LLC	US Job Creation Due to Nuclear Power Resurgence in the United States (analytical model)
13	2002	B. Heavner and S. Churchill—CALPIRG (California Public Interest Research Group) Charitable Trust	Job Growth from Renewable Energy Development in California (I/O model)
14	2001	G. Simons (California Energy Commission) and T. Peterson (EPRI)	California Renewable Technology Market and Benefits Assessment (analytical model)
15	2001	Virender Singh of Renewable Energy Policy Project (REPP) and Jeffrey Fehrs of BBC Research and Consulting	The Work that Goes into Renewable Energy (analytical model)

Table 2
Comparison of jobs/MWp, jobs/MWa and job-years/GWh across technologies.

Work-hours per year	2000	Capacity factor (%)	Equipment lifetime (years)	Employment components			Average employment over life of facility							
							Total jobs/MWp		Total jobs/MWa		Total job-years/GWh			
Energy technology	Source of numbers			CIM (job-years/MWp)	O&M (jobs/MWp)	Fuel extraction and processing (job-years/GWh)	CIM	O&M and fuel processing	CIM	O&M and fuel processing	CIM	O&M and fuel processing	Total	Avg
Biomass 1	EPRI 2001	85	40	4.29	1.53	0.00	0.11	1.53	0.13	1.80	0.01	0.21	0.22	0.21
Biomass 2	REPP 2001	85	40	8.50	0.24	0.13	0.21	1.21	0.25	1.42	0.03	0.16	0.19	
Geothermal 1	WGA 2005	90	40	6.43	1.79	0.00	0.16	1.79	0.18	1.98	0.02	0.23	0.25	0.25
Geothermal 2	CALPIRG 2002	90	40	17.50	1.70	0.00	0.44	1.70	0.49	1.89	0.06	0.22	0.27	
Geothermal 3	EPRI 2001	90	40	4.00	1.67	0.00	0.10	1.67	0.11	1.86	0.01	0.21	0.22	
Landfill Gas 1	CALPIRG 2002	85	40	21.30	7.80	0.00	0.53	7.80	0.63	9.18	0.07	1.05	1.12	0.72
Landfill Gas 2	EPRI 2001	85	40	3.71	2.28	0.00	0.09	2.28	0.11	2.68	0.01	0.31	0.32	
Small Hydro	EPRI 2001	55	40	5.71	1.14	0.00	0.14	1.14	0.26	2.07	0.03	0.24	0.27	0.27
Solar PV 1	EPIA/Greenpeace 2006	20	25	37.00	1.00	0.00	1.48	1.00	7.40	5.00	0.84	0.57	1.42	0.87
Solar PV 2	REPP 2006	20	25	32.34	0.37	0.00	1.29	0.37	6.47	1.85	0.74	0.21	0.95	
Solar PV 3	EPRI 2001	20	25	7.14	0.12	0.00	0.29	0.12	1.43	0.60	0.16	0.07	0.23	
Solar Thermal 1	Skyfuels/NREL 2009	40	25	10.31	1.00	0.00	0.41	1.00	1.03	2.50	0.12	0.29	0.40	0.23
Solar Thermal 2	NREL 2006	40	25	4.50	0.38	0.00	0.18	0.38	0.45	0.95	0.05	0.11	0.16	
Solar Thermal 3	EPRI 2001	40	25	5.71	0.22	0.00	0.23	0.22	0.57	0.55	0.07	0.06	0.13	
Wind 1	EWEA 2008	35	25	10.10	0.40	0.00	0.40	0.40	1.15	1.14	0.13	0.13	0.26	0.17
Wind 2	REPP 2006	35	25	3.80	0.14	0.00	0.15	0.14	0.43	0.41	0.05	0.05	0.10	
Wind 3	McKinsey 2006	35	25	10.96	0.18	0.00	0.44	0.18	1.25	0.50	0.14	0.06	0.20	
Wind 4	CALPIRG 2002	35	25	7.40	0.20	0.00	0.30	0.20	0.85	0.57	0.10	0.07	0.16	
Wind 5	EPRI 2001	35	25	2.57	0.29	0.00	0.10	0.29	0.29	0.83	0.03	0.09	0.13	
Carbon Capture & Storage	Friedmann, 2009	80	40	20.48	0.31	0.06	0.51	0.73	0.64	0.91	0.07	0.10	0.18	0.18
Nuclear	INEEL 2004	90	40	15.20	0.70	0.00	0.38	0.70	0.42	0.78	0.05	0.09	0.14	0.14
Coal	REPP 2001	80	40	8.50	0.18	0.06	0.21	0.59	0.27	0.74	0.03	0.08	0.11	0.11
Natural Gas	CALPIRG 2002	85	40	1.02	0.10	0.09	0.03	0.77	0.03	0.91	0.00	0.10	0.11	0.11
Energy Efficiency 1	ACEEE 2008	100	20										0.17	0.38
Energy Efficiency 2	Goldemberg, 2009	100	20										0.59	

Appendix A. A complication is that the studies report their data in different forms using different methods and in different units. We follow the approach described in detail in Kammen (2004) to normalize the data from each study. A brief description of the approach is given here.

We consider two job function groupings: (1) construction, installation, and manufacturing (CIM) and (2) operations, maintenance, and fuel processing. Items in the first group are typically reported in "job-years per MW installed" or equivalently, "job-years per peak (or nameplate) MW" while the second group is reported in jobs per peak MW over the lifetime of the plant. How then to best combine one-time employment (e.g. installation) with ongoing employment? We opt to average over the life of the project.

By converting the CIM job-years per peak MW to *average* jobs per megawatt over the lifetime of the plant, the two can be combined. This assumes that a large number of facilities of a given type are being built (and eventually replaced) throughout the economy, which is a reasonable assumption for many renewable energy sources. Next, the total jobs per peak megawatt (MWp) is normalized to total jobs per average megawatt (MWa) by dividing jobs per peak megawatt by the capacity factor, where the capacity factor is the fraction of a year that the facility is in operation. This follows since lower capacity technologies will have to build more plants than higher capacity technologies to deliver the same power.

This averaging technique has the advantage of providing a simple metric for comparing employment for different technologies. Annual employment for a given technology is calculated based on only two parameters: annual output energy (in GWh) and the employment multiplier (in job-years per GWh). This simplicity enables a straightforward implementation of a jobs model without having to track the exact details of combining one-time employment activities with ongoing employment on a year to year basis, and the approach converges to the correct number of cumulative job-years after several years. The disadvantage of this technique, however, is that it underestimates total employment for a technology that is growing rapidly (e.g. renewable energy technologies), while it overestimates employment for a technology that is reducing capacity.

We also note that some studies were consulted but not included in this report due to lack of supporting information for their job estimates. Moreover, existing studies may not cover all components of employment considered (manufacturing, construction, installation, operations and maintenance, and fuel processing). The more comprehensive papers, which presented jobs/MW data along with person-years data, were used most extensively.

Table 2 presents a detailed job generation summary of the studies that were analyzed. Some technologies were represented by many studies (solar and wind); some technologies were not studied as frequently (geothermal, biomass); and for some, job estimates were not readily available (municipal solid waste). For the latter we adopted placeholder values of 0.15 job-years/GWh as a conservative estimate at the lower range of renewable and low carbon multipliers.

A typical calculation for direct employment is described for the example of a Vestas wind plant in the US (McKinsey, 2006). From the report, a 228 MW (peak) onshore wind farm generates 500 jobs in development and installation for 5 years and 40 O&M jobs for 20 years. This translates to 2500 job-years for development/installation and 800 job-years for O&M. Dividing these numbers by 25 years for lifetime gives the average number of jobs per peak MW over the life of the plant. Dividing by an estimated 35% capacity factor for wind plants gives the result 1.25 jobs per average MW for CIM and 0.40 jobs per average MW for O&M. The reference report also provides employment estimates for offshore wind farms and both data points are factored into the final data entry in Table 2. Note that this example does not explicitly include manufacturing jobs in wind turbine production and thus the job multiplier for CIM is probably an underestimate for direct jobs as defined above.

For CCS, we considered three options for CCS implementation: post-combustion capture retrofit for pulverized coal, post-combustion retrofit for natural gas, and pre-combustion capture design for IGCC (Friedmann, 2009). Employment impact for the first two options were considered to be additive to existing coal and natural gas employment while jobs for IGCC CCS were treated as stand-alone since new plant construction is involved. Resultant job numbers for the three options are 0.17, 0.22, and 0.16 job-years/GWh, respectively, and the average of these results is taken in Table 2.

In the energy efficiency sector we used a multiplier of 0.38 job-years/GWh of energy savings that is the average of Goldemberg (2009) and Laitner and McKinney (2008). We assume that the majority of jobs are induced jobs (90%) and only 10% are direct jobs associated with energy efficiency products or installation, an assumption used by the ACEEE in the past (Geller, 1992). The business-as-usual (BAU) case of energy demand already assumes a certain amount of energy savings and energy efficiency-induced jobs due to existing building codes and appliance standards, industry improvement, and implicit programs (EPRI, 2009), so our energy efficiency net job gains are additional jobs above and beyond this implicit baseline level.

Fig. 1 shows the average and range of direct employment multipliers per unit energy for ten different energy technologies based on the studies considered in Table 1. A large amount of variation is seen in many technologies, particularly solar PV. This may be due to implicit differences in data collection and analysis methodology between different studies. For technologies with more than one study, our approach of averaging the studies thus reduces the weight of any one study. Solar PV has the highest average job multiplier with a large gap between it and the next highest renewable technologies (geothermal and solar thermal).

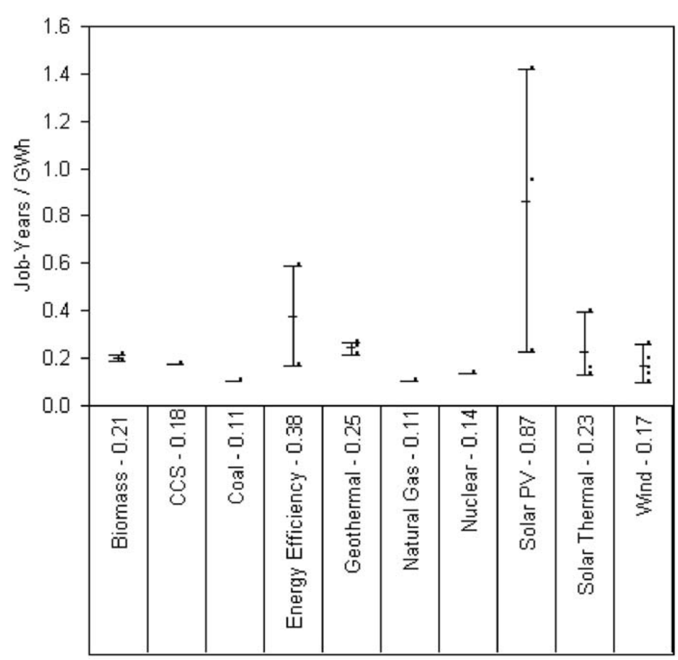

Fig. 1. Average and range of direct employment multipliers for ten different energy technologies based on the studies from Table 1.

In part, this is likely due to the many discrete panel installations contributing to solar PV development (as compared to a single location for a wind farm).

Comparing among the technologies, we find a spread among the distribution of jobs between CIM and O&M. Biomass, natural gas, and coal are seen to have the largest fuel processing requirement. We were not able to find a direct estimate for nuclear power fuel processing requirements. Solar and wind are found to have the highest ratio of CIM to O&M jobs and for solar this is likely due to a large installation component of employment.

5. Analytical model description

In this section we describe an Excel-based analytical model for the US power sector designed to estimate net employment impacts under various user-defined energy supply scenarios for the 2009–2030 time frame. The model synthesizes data from the 15 job studies summarized above covering renewable energy, energy efficiency, carbon capture and storage and nuclear power in addition to coal and natural gas. We utilize the normalization approach of taking average employment per unit energy produced over plant lifetime, as described in Section 4. In addition to these average employment multipliers provided by the meta-study, the user can specify assumptions for the following three supply sectors in the model: (1) energy efficiency assumption to 2030; (2) RPS percentage and technology portfolio contributions; and (3) low carbon percentage and portfolio contributions. Unlike other job studies, job losses in the coal and natural gas industry are modeled to project net employment impacts. Combinations of factors are readily modeled, e.g. the number of jobs with both increased EE and increased RE. The model thus provides guidance and quantification to the three key questions posed in Section 1.

We take as our baseline the December 2008 Energy Information Administration (EIA) roadmap of electricity generation and projected electricity source contributions out to 2030. The baseline or BAU numbers of direct and indirect jobs are calculated with this amount of generation and partitioning of energy sources. Our calculator then computes how the job picture shifts with greater or lower energy efficiency, varying amounts of renewable energy, and differing portfolio mixes of RPS and low carbon technologies.

For the renewable and low carbon technology sectors we include only direct and indirect jobs since most studies in these two sectors utilize analytical based job generation models and do not include estimates of induced jobs. For indirect jobs, we took the average multiplier from three reports, a solar study from the United States (Bezdek, 2007), a European wind report (EWEA, 2009), and a renewable energy study from Germany (Staiss, 2006). This gave an indirect multiplier of 0.9 that for simplicity was applied to all technologies. (For example if the direct multiplier for technology B is 0.2 job-years/GWh, the indirect multiplier is $0.2\times0.9=0.18$ job-years/GWh and the total jobs produced is 0.38 job-years/GWh). Clearly this is a rough approximation for indirect jobs and we expect variation between technologies. Some reports included much higher estimates for indirect jobs (Kenley, 2004 nuclear study and Stoddard, 2006 solar thermal report) but we took a more conservative average approach to avoid double counting direct and indirect jobs.

A net job creation number for the renewable and low carbon technology sectors is calculated by factoring in job loss impacts to the coal and natural gas industry due to increases in renewable energy or low carbon technologies. Previous studies have focused on gross renewable energy job creation under various RPS or technology scenarios, e.g. "a 20% national RPS in 2020 produces 160,000 direct jobs." For this work, we ask what amount of net jobs can be created over and above what is projected from existing policies and accounting for any job losses that may occur from reductions in the supply of electricity from coal and natural gas.

For energy efficiency, we include direct, indirect and induced jobs, or equivalently net jobs created per unit energy saved. This may bias the results in favor of energy efficiency. However, we were not comfortable making an analytical estimate for induced employment for renewable energy and low carbon sources since most studies in these two sectors do not include estimates of induced jobs. Energy efficiency studies, on the other hand, tend to utilize I/O models and their authors argue that most of the employment from energy efficiency investment is from energy bill savings and subsequent-induced employment, and their estimates are included here.

In addition to the direct and indirect job multipliers described above, our model accepts the following user inputs: the annual rate of increase of electricity demand (BAU is about 0.74%) to 2030, the target RPS and low carbon supply percentages in 2020 and 2030, and the technology components (wind, biomass, etc) for the RPS and low carbon supply in 2020 and 2030. Overall electricity demand is then translated to the various supply sources as specified by user input, and a mapping of these supply sources to overall employment is performed using the multipliers from Table 2. Net employment can then be calculated by taking the difference between the modeled scenario and the BAU scenario based on EIA reference data for electricity demand and supply sources. A screen shot of the model's input deck is shown in Table 3.

We assume electricity demand reductions are provided by energy efficiency and not from reduced energy usage due to other effects such as conservation or behavior changes. The supply of low carbon sources such as nuclear and hydro is also assumed to not decrease over time beyond BAU levels, so that any reduction in energy demand over BAU is assumed to be taken from coal or natural gas. This implies that the absolute percentage of nuclear and hydro power will increase over time as more energy efficiency is achieved even with no new nuclear or hydro construction.

Table 3
Sample screen shot of jobs model showing input parameters for RPS and low carbon fraction and components in 2020.

Time frame	2009–2030	
Generation assumptions		BAU
Electricity increase in 2030 over 2009 (%)	***BAU***	24%
RPS assumptions		BAU
2020 RPS % of total gen.	***20.0%***	7.4%
2030 RPS % of total gen.	***30.0%***	9.1%
RPS portfolio—2020	% total generation	BAU 2020
Biomass	***9.5%***	3.5%
Hydro (small)	***1.5%***	0.6%
Geothermal	***1.1%***	0.4%
Municipal solid waste	***1.3%***	0.5%
Solar PV	***1.0%***	0.4%
Solar thermal	***0.1%***	0.0%
Wind	***5.5%***	2.0%
RPS %	**20.0%**	7.4%
Low carbon assumptions		BAU
2020 low carbon % of total gen.	***24.6%***	24.6%
2030 low carbon % of total gen.	***22.6%***	22.6%
Low carbon portfolio—2020		BAU
Carbon capture and storage (% coal gen.)	***0.0%***	0.0%
Conventional hydropower	***5.9%***	5.9%
Nuclear (% to include in RPS)	***18.7%***	18.7%
Low carbon %	**24.6%**	24.6%

Inputs are in bold italics.

Our model assumes that transmission, distribution, and storage capacity are not constraints, especially when projecting high percentages of RE and low carbon sources. This assumption also leads to the simplification that all renewable power generation displaces coal and natural gas, which may not be the case today or in the near future for intermittent sources such as wind power in the absence of large-scale storage. Clearly, significant investment in both infrastructure and research and development (R&D) is needed to enable this and both the electricity grid and storage have been targeted in the US federal government's 2009 stimulus package.

This work does not include analysis of leakage and jobs that are exported, i.e. all jobs are assumed to reside within the country of interest, nor is the potential increase in jobs from export of manufactured goods considered (Lehr et al., 2008). The concern for the former is that manufacturing jobs may be predominantly exported to lower labor cost countries such as China or Vietnam. While design and development jobs ("front end") and maintenance and service jobs ("back end") remain onshore, a "hollowing out" of the manufacturing sector might occur in the middle. This effect has not been thoroughly studied for clean energy and may vary by technology. Manufacturing wind turbines on-site is often more economical than producing them for export and accordingly, Danish turbine maker Vestas is expanding aggressively in the United States (Glader, 2009). Nor do we consider local vs. national employment effects. It is possible that some regions of the country would see heavier job losses than others, so policies could be tailored to address these inequalities for example through targeted subsidies or job re-training programs. For example, West Virginia may be hit disproportionately hard by job losses due to its coal mining industry while California may benefit relatively more due to its solar resource. Other references show that a national increase in renewable energy can benefit all regions of the adopting country (Staiss 2006).

We do not explore detailed cost benefit analysis. For example, if more renewable energy is built, electricity prices may become more expensive, increasing costs for businesses and reducing employment in those businesses. However, overall costs are calculated to be relatively small fraction of GDP in several studies (see for example McLennan Magasanik, 2009). Moreover, a full cost benefit analysis would include other benefits from cleaner energy which are not typically included (e.g. better health, environmental benefits). Rather than focusing on a single sector such as wind or solar, some studies consider a portfolio of greenhouse gas reduction policies with the assumption that a cap and trade system for greenhouse gases is in place. For example, the California AB32 Global Warming Solutions Act includes a suite of policies including vehicle standards, energy efficiency programs (e.g. building codes, appliance standards, and combined heat and power), and renewable energy mandates (Roland-Holst, 2008). In this way, more cost effective measures such as energy efficiency can compensate for less cost effective but rapidly growing sectors such as solar PV. The net economic impacts then become highly dependent on the rate of technological innovation, but if innovation is assumed to follow historical trends and strong policies are in place for energy use reduction then significant job growth can result.

6. Discussion of model results

Annual employment for energy efficiency beyond BAU are plotted in Fig. 2 for two electricity generation scenarios. The "medium-EE" case represents 50% lower annual growth rate than BAU or 0.37% annual growth in electricity generation versus 0.74% for BAU, and the "flat energy" case represents no increase in annual electricity generation (0.74% lower growth than BAU). Both curves show steadily increasing job growth as the total energy saved increases steadily over time with features in the two curves reflecting the BAU reference energy demand data.

Cumulative job-years from 2009 through 2030 versus annual improvement in energy efficiency for various energy supply approaches are shown in Figs. 3–5. Cumulative job-years are computed by adding the job-years above BAU each year for a given scenario. This metric is often implicitly or explicitly quoted in jobs studies for a given time frame and we utilize it here to compare different technologies. We project employment to 2030 since nuclear and CCS have long lead times and we would not expect appreciable gains by 2020. The three marker points on each curve represent BAU, medium-EE, and flat energy cases, respectively.

For the medium-EE case, half-a-million total jobs are generated from 2009 to 2020 and 1.9 million total job-years from 2009 to 2030 (Fig. 3), while for the flat energy case, we project 1 million and just under 4 million job-years, respectively This is in the absence of any other changes from BAU supply sources.

Employment generation by RPS as function of EE for various RPS target percentages in 2030 is shown in Fig. 4a. For a fixed target RPS percentage in 2030, total RPS job-years decrease with improved EE since as the overall electricity generation "pie" is reduced, the absolute amount of renewable energy is reduced.

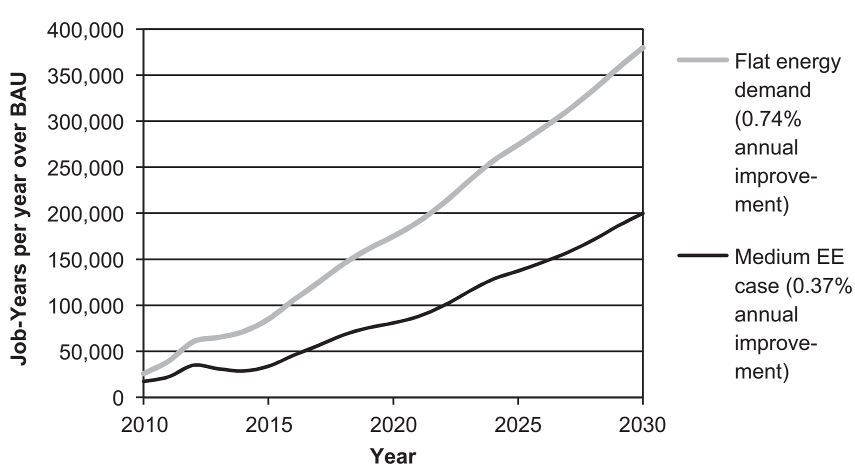

Fig. 2. Annual job-years generated over BAU due to energy efficiency improvement.

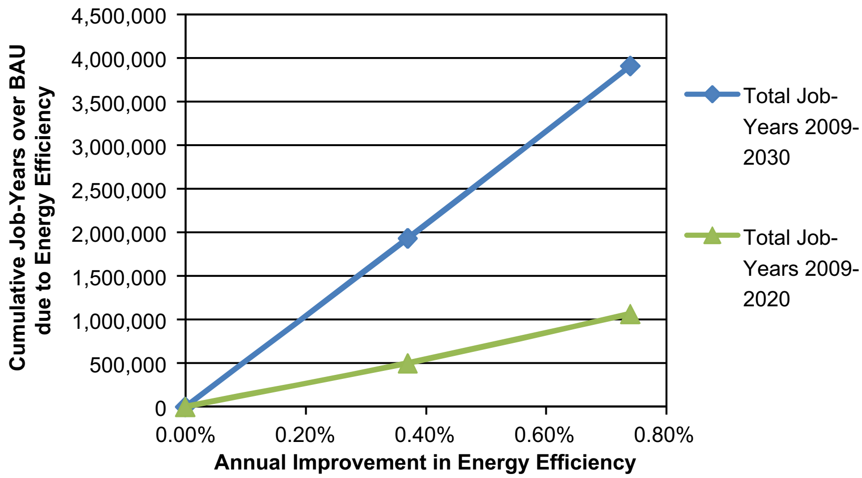

Fig. 3. Cumulative job-years over BAU due to energy efficiency improvement for 2009–2020 and 2009–2030, respectively.

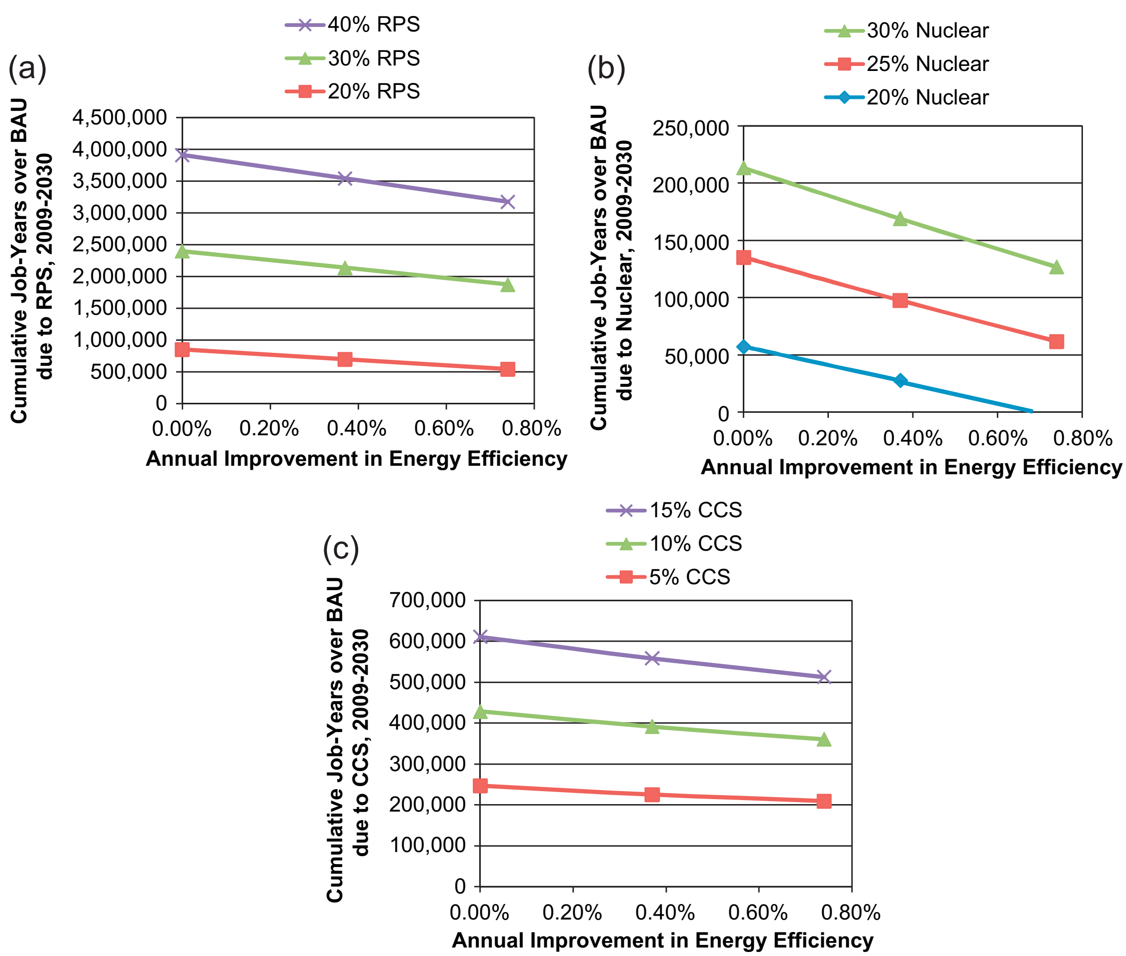

Fig. 4. (a) Cumulative job-years for 2009–2030 over BAU due to RPS for various RPS targets in 2030. (b) Cumulative job-years for 2009–2030 over BAU due to nuclear power for various nuclear generation targets in 2030. (c) Cumulative job-years for 2009–2030 over BAU due to CCS for various CCS targets in 2030.

RPS targets of 10%, 20%, and 30% in 2020 are assumed for RPS targets of 20%, 30%, and 40% in 2030, respectively. Coal and natural gas jobs are lost but at a lower rate than renewable energy job are created. While the model allows for the flexibility of changing the portfolio of RPS constituent technology percentages, RPS calculations in Fig. 4a assume a BAU "portfolio" distribution in 2020, i.e. the makeup of the RPS replicates the BAU constituent percentages in 2020 (approximately 47% biomass, 27% wind, 8% small hydro, 7% municipal solid waste, 6% geothermal, 5% solar PV, and 1% solar thermal). 2030 RPS portfolio components are then scaled by the proportional increase in overall RPS from 2020 to 2030. Note that by changing the constituent technology target percentages in 2020 and 2030, job numbers would shift either higher or lower depending on portfolio distribution and relative

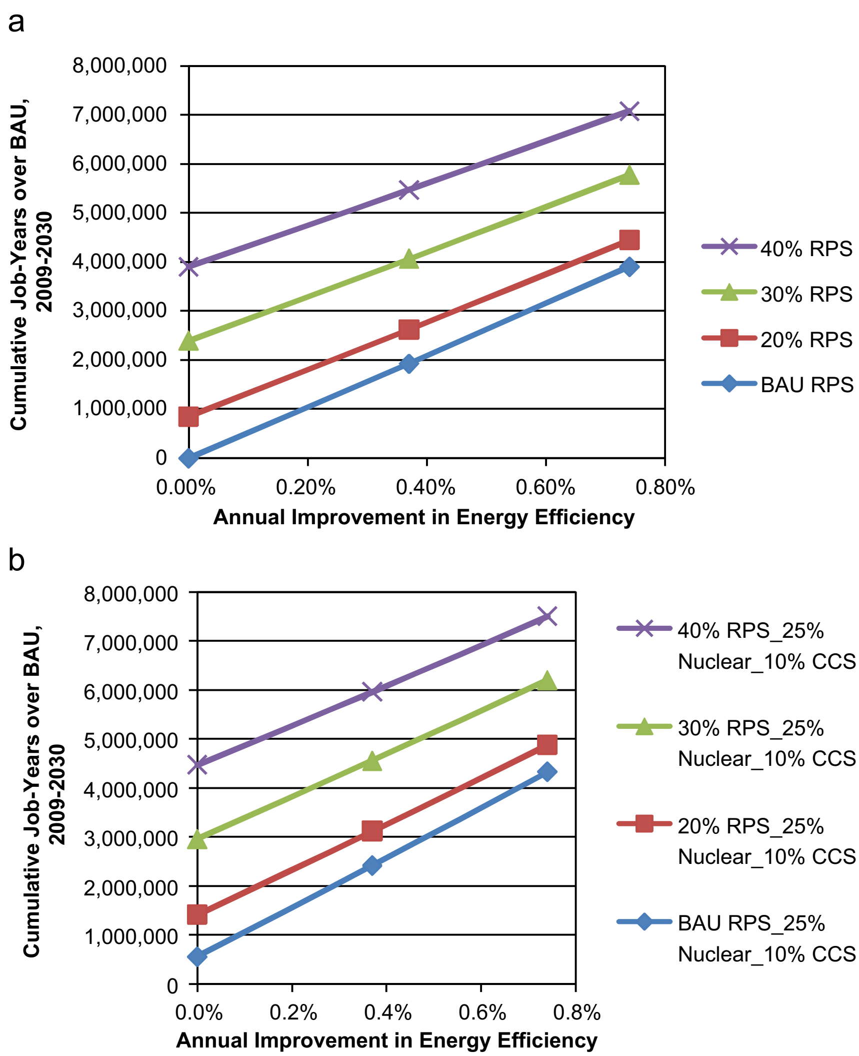

Fig. 5. (a) Cumulative job-years over BAU for 2009–2030 due to energy efficiency and RPS for various RPS targets in 2030. (b) Cumulative job-years over BAU from 2009–2030 due to energy efficiency, RPS, nuclear power, and CCS, for various RPS targets in 2030 and assuming 25% nuclear generation and 10% CCS in 2030, respectively.

job multipliers. In particular, if geothermal, solar, or solar thermal targets are higher than BAU levels, job generation will increase since these three technologies have the highest job multipliers among renewable energy technologies.

Similar plots are shown in Fig. 4b and c for nuclear power and CCS, respectively. For example, a 20% (25%) nuclear fraction of overall generation in 2030 with BAU EE is projected to generate 60,000 (140,000) job-years. Nuclear employment scenarios assume that 2020 nuclear generation meets the "high growth" EIA target of 112 GW in the US in 2020 or 19.2% of overall generation (EIA, 2009).

Nuclear numbers are relatively low in our model. Nuclear jobs may be underestimated based on the nuclear references not including some job categories (design, site work, licensing, oversight, waste management, decontamination, and decommissioning). The nuclear study (Kenley, 2004) also estimated large indirect and induced job multipliers that were not fully captured in this report.

The CCS employment curves assume CCS achieves 1% of overall generation in 2020. For reference, IEA has set goals for 20 large-scale demonstration plants for CCS globally by 2020 and 9% of power generation by 2030 under an "emission stabilization" scenario (IEA, 2009). Currently CCS has a lack of viable demonstration plants and large uncertainties in commercial viability, technology, and regulatory environment. Unless there are major national initiatives and expansion coupled with rapid technological progress, we do not expect a high penetration rate of the technology in the next decade.

The cumulative job plots for 2009–2030 are then additive. For example, Fig. 5a shows EE+RPS employment for various RPS targets in 2030. For a 2030 RPS target of 30% and medium-EE improvement, employment is projected at 4 million, or a similar number of jobs could be achieved with BAU RPS and flat energy demand. About a half-million job-years are added with the addition of 25% nuclear generation and 10% CCS in 2030, respectively (Fig. 5b). This scenario would translate to an electricity sector that has 65% of its supply from renewable or low carbon sources.

The addition of learning curves to our model could lead to a decreasing of the jobs dividend over time as real capital costs fall. Many studies exclude learning curve information beyond a qualitative discussion. The DOE (2008) wind study excludes learning curves from their economic development model and utilizes a "static model that does not taken into account improvements in industry productivity." For solar PV, the European Photo Voltaic Industry Association and Greenpeace (EPIA/Greenpeace 2006) project CIM employment to decrease by about 25% from 2010 to 2020 due to industry learning and cost reduction. Assuming a flat growth rate for O&M jobs, this would lead to a 17% lower employment multiplier in 2020. This may provide an upper bound on the total employment reduction from our projections since solar PV has generally shown a faster learning rate than other RE sources.

From a policy perspective, it is interesting to note that although the construction of turbines, solar panels, or other pieces of equipment can be easily done elsewhere, the installation of any technology necessarily creates local jobs. While coal and natural gas plants are typically centralized, large installations and renewable sources can be used for utility scale developments, distributed renewable sources can provide local "distributed" employment with environmental and financial advantages such as shorter lead times and lower initial cost (Lovins, 1976). As a result, renewable energy can provide much-needed opportunities for domestic job growth in developing countries. For example, UNEP's (2009) report on green jobs cites an example of women and youth in Bangladesh getting jobs as solar technicians. These jobs have the doubly positive effect of both giving the local people jobs, as well as improving the eco-friendliness of the local economies. Similar job creation has been observed in Kenya where there is a thriving local economy of solar module sales and installation (Jacobson and Kammen, 2007). This incremental penetration of local economies with renewable sources can often provide a faster path to economic development and electrification than large-scale fossil fuel power plants.

Green jobs can also address the specific concern that skilled jobs are often sent abroad. According to the American Solar Energy Society green jobs report (ASES, 2008), job growth in the renewable energy and energy efficiency industries is biased towards technical, scientific, professional, and skilled workers. For example, wind energy is a reliable job creator for both skilled and unskilled labor, as discussed by the European Wind Energy Association report (EWEA, 2009). The wind turbines themselves necessitate construction and installation, as well as longer-term maintenance work. Additionally, the creation of wind farms requires planning, obtaining of permits, and ongoing supervision of the turbines. Thus the wind industry employs a range of skilled and professional workers, from engineers, to meteorologists, to site managers that is not easily outsourced. The solar industry similarly employs a range of workers, and the numerous technical skills involved in the creation of solar PV necessitate skilled labor.

To summarize our results, we find that the renewable energy and low carbon sector generates more jobs than the fossil fuel-based sector per unit of energy delivered (i.e. per GWh generated). Many sectors can contribute to both very low CO_2 emissions and significant job creation and a combination of technologies may be necessary to meet GhG emissions targets. A national RPS of 30% in 2030 coupled with "medium-EE" scenario (0.37% reduction in annual energy growth rate) can generate over 4 million job-years, and further increasing nuclear generation to 25% and CCS to 10% of total generation in 2030 can generate an additional 500,000 job-years.

7. Conclusion

There are three key arguments for building a domestic clean energy industry: improved energy security, environmental protection and benefits, and as a potential engine for economic growth. Indeed, employment benefits of renewable energy could go to countries that start early and build strong export markets. Job creation from clean energy can provide an even larger benefit in developing nations that lack the resources for large centralized power plants. Consistent and long-term policies are a key requirement for growth of a "green economy" and carbon pricing is essential for long-term technology and policy change.

This work provides policy makers with a framework for understanding various green jobs reports and presents a normalized methodology for comparing employment impacts for various energy supply sources. We stress that data aggregation of these reports should focus on uniform methodology of job metrics and definitions, and analysts need to be careful when comparing technologies and to be specific about the timing and duration of employment.

We also present a simple spreadsheet model that policy makers in the US can use to project job generation over time as a function of varying targets in energy efficiency, renewable energy, and low carbon sources. Such a model can be easily adopted to other countries or markets, although the job multiplier data is probably most applicable to developed countries.

We find that all renewable energy and low carbon sources generate more jobs than the fossil fuel sector per unit of energy delivered while the type of employment differs between technologies (e.g. manufacturing vs. resource extraction) and the timing and location of employment may differ within a given country or geography. This information can be useful for policy makers who are designing long range energy policies or short-term government programs to provide economic stimulus or incentives for direct employment.

Energy efficiency investment offers a high payoff in induced jobs and is generally the least cost and often the most readily implementable approach. More energy efficiency can diminish the need for both additional fossil fuel plants and new renewable energy sources. Our study thus offers additional support for aggressive energy efficiency policies such as reduction of market barriers, improving public awareness and education, and facilitating EE financing.

For areas of future work, a cost benefit analysis of various investments in RE would be useful, taking into account the cost of carbon as well as environmental, health, and security benefits. Economic modeling to include full industry-to-industry interactions would bring this work beyond the simple employment model projections presented here.

Our analysis did not disaggregate the location of manufacturing jobs across sectors and this information would be very useful for policy makers. Important issues include the regional and international distribution of jobs, job-needs assessments and job training programs across job-types and sectors, manufacturing policies, and financing issues such as subsidies and public/private project financing. More discussion on the most effective policies to promote green jobs in the context of EE, RE, and low carbon sources should be pursued.

An expanded technology analysis and envelope would include more up to date information on coal and natural gas employment estimates, further elaboration on CCS costs and employment benefits, and inclusion of "smart grid", storage, ocean energy and other emerging technologies. We alluded to the impact of learning rates on employment multipliers but a fuller discussion of time dependencies is clearly appropriate. For example in addition to industry learning rates, are there any inflection points in capital or labor requirements as RE grows as a fraction of overall power supply, or are there any trends in the outsourcing of manufacturing jobs?

Expansion of this analysis should include developing nations. We expect similar range of employment numbers in the developed world but there may be material differences or greater changes over time in the developing world. Some areas that may warrant additional treatment in the developing world are "informal economy" sectors such as recycling that may lend

Table A1

No.	Year	Author—affiliation	Study	Method	Scenarios used
1	2009	Isabel Blanco and Christian Kjaer—European Wind Energy Association (EWEA)	Wind at Work: Wind energy and job creation in the EU	Assumes that wind energy creates 10 jobs (man years) per MW of annual installation, turbine manufacturing, component manufacturing, wind farm development, installation and indirect employment. O&M work contributes an additional 0.4 jobs/MW of total installed capacity.	Wind sector employment in EU increasing from 154 k in 2007 to 377 k in 2030. 180 GW of wind energy will be operating in the EU in 2020 and 300 GW by the end of 2030. Over that period, an increasing share of the installations will be offshore.
2	2009	Julio Friedmann—Lawrence Livermore National Laboratory	Personal communcation, 13 February 2009, on carbon capture and storage job impacts	Model three paths for CCS: (1) pulverized coal; (2) IGCC; (3) natural gas carbon capture	Consider situation where all three paths occur and take average of employment effects
3	2009	José Goldemberg—State of São Paulo, Brazil	Personal communcation, 13 February 2009, on Energy efficiency and jobs data		
4	2009	SkyFuels and National Renewable Energy Laboratory	Personal communication, 21 March 2009, on Solar Thermal jobs data	Jobs and Economic Development Impact ("JEDI") model	1000 MW online by 2014, total projected CSP project job creation through 2014–33,300 FTE jobs
5	2008	John A. "Skip" Laitner and Vanessa McKinney—American Council for an Energy Efficient Economy	Positive Returns: State Energy Efficiency Analyses Can Inform US Energy Policy Assessments	Summary of state level studies. I/O model based with policies translated to investment and estimated changes in energy usage. Cost benefit analysis for resultant savings, re-directed spending to more labor intensive sectors and net employment gain.	Based on a review of 48 different assessments, this report highlights the findings of a wide variety of studies that explore the many possibilities of further gains in energy efficiency, especially at the regional and state level. The studies reviewed here show an average 23% efficiency gain with a nearly 2 to 1 benefit–cost ratio. From analyzing this set of studies, a 20–30% gain in energy efficiency estimated within the US economy might lead to a net gain of 500,000–1,500,000 jobs by 2030.
6	2006	Winfried Hoffman, Sven Teske—European Photovoltaic Industry Association (EPIA) and Greenpeace	Solar Generation: Solar Electricity for Over One Billion People and Two Million Jobs by 2020	Information provided by industry	Global PV systems output 589 TWh in 2025, 276 TWh in 2020
7	2006	McKinsey Consulting	Windpower and Development: Jobs, Industry and Export	Jobs generated by an onshore and on offshore park, considering development and installation jobs and operations and maintenance jobs	
8	2006	George Sterzinger—Renewable Energy Policy Project (REPP)	Jobs and Renewable Energy Project	Used enhanced version of 2002 REPP Jobs Calculator and Nevada RPS standards to yield labor information about wind, PV, biomass co-firing, and geothermal technologies	
9	2006	L. Stoddard, J. Abiecunas, R. O'Connell—National Renewable Energy Laboratory (NREL)	Economic, Energy, and Environmental Benefits of Concentrating Solar Power in California	Study focusing on economic return, energy supply impact, and environmental benefits of CSP (Concentrating Solar Power) in California	100 MW parabolic trough plant with 6 hours of storage was used as a representative CSP plant. Cumulative deployment scenarios of 2100 MW and 4000 MW were assumed for 2008–2020. Assumed that technological improvements would result in 150 and 200 MW plants in 2011 and 2015, respectively. Included learning curve estimations based on NREL data.

Table A1 (*continued*)

No.	Year	Author—affiliation	Study	Method	Scenarios used
10	2005	Doug Arent, John Tschirhart, Dick Watson—Western Governors' Association: Geothermal Task Force (WGA)	Clean and Diversified Energy Initiative (CDEAC)	Study synthesizing views and research of 24 members of geothermal community	
11	2004	Daniel M. Kammen, Kamal Kapadia, and Matthias Fripp—Energy and Resources Group, Universtiy of California, Berkeley	Putting Renewables to Work: How Many Jobs Can the Clean Energy Industry Generate?	Meta-analysis of 13 studies on renewable energy job creation. Normalization of job creation by average power over lifetime of plant.	Comparison of average employment from five electricity generation scenarios. Considers photovoltaics, wind, biomass and coal.
12	2004	C.R. Kenley, et al.—Idaho National Engineering and Environmental Laboratory (INEEL) and Bechtel BWXT Idaho, LLC	US Job Creation Due to Nuclear Power Resurgence in the United States	Industry/expert estimates for manufacturing and construction/ operations jobs: Indirect/induced jobs via NEI (Nuclear Energy Institute) economic impact studies and US Census Data IMPLAN modeling tool	33–41 Gen III units, 1200–1500 Mwe for 50,000 Mwe by 2020. Construction from 2009–2024. 1–2 plants/yr online starting 2014 to 4–5 plants online 2020–2024. 40,000 manufacturing jobs, 80,000 construction/operations jobs and 500,000 total with direct: indirect: induced ratios of 1:1.7:1.7.
13	2002	Heavner and ChurchillHeavner and Churchill—CALPIRG (California Public Interest Research Group) Charitable Trust	Job Growth from Renewable Energy Development in California	Report detailing job creation potential of renewable energy industry in California. Data is yielded from CEC (California Energy Commission) research, and a CEC funded EPRI (Electric Power Research Institute) study from 2001.	Comparison of employment projections from CEC and data from existing plants was used to derive employment rates for wind, geothermal, solar PV, solar thermal, and landfill/ digester gas
14	2001	G. Simons (California Energy Commission) and T. Peterson (EPRI)	California Renewable Technology Market and Benefits Assessment	Report includes estimates of job creation from renewable energy development projected in California to 2011. Based on existing and planned projects and market outlook of project developers and equipment manufacturers.	Three scenarios considered with average prices received by renewable power at $0.041/ kWh, $0.068/kWh, and $0.091/ kWh, respectively, corresponding to projected 10%, 14%, 20% cumulative contribution to California electricity generation.
15	2001	Virender Singh of Renewable Energy Policy Project (REPP) and Jeffrey Fehrs of BBC Research and Consulting	The Work that Goes into Renewable Energy	Study calculates jobs in person-years/MW and person-years/$ invested. Uses a simple model, does not take into account multiplier effects as an I–O model would. Authors collected primary employment data from companies in the solar PV, wind energy and coal sectors, and used project scenario numbers for biomass energy. Study takes in account jobs in manufacture, transport and delivery, construction and installation, and O&M.	None

themselves to bottom up analysis, issues of biomass sustainability, micro-grids, and distributed power and generation.

Appendix A. Summary of studies reviewed

See Table A1.

Appendix B. Notes on calculations for employment figures in Table 2

1. EWEA (2009) wind data taken directly from report (10.1 direct job-years per MW installed and 0.40 jobs/MW for O&M).
2. Friedmann (2009) numbers based on three technology options (pulverized coal, IGCC, natural gas carbon capture) and include design, manufacture, construction, site work, post-combustion capture, drilling, and O&M.
3. Skyfuels/NREL (2009) direct numbers were provided (1000 MW online by 2014, total projected CSP project job creation through 2014–33,300 FTE jobs).
4. Laitner and McKinney (2008) energy efficiency multiplier from direct parameter provided in text.
5. EPIA/Greenpeace (2006) solar PV data is based on low-end employment estimates for manufacturing, service, installation, and maintenance on page 32 of report.

6. McKinsey (2006) wind data taken directly from Vestas example and averaging of onshore and offshore wind farm employment.
7. The REPP (2006) solar and wind data is based upon data collected from various Nevada groups and is analyzed in the paper with relation to the Nevada RPS using the tables on page 7 of the paper. O&M employment was adjusted to account for all O&M employment over facility lifetimes.
8. NREL 2006 solar thermal data taken from Tables 5–7 of report for construction and operation employment.
9. WGA 2006 geothermal data based on ‘‘New geothermal power capacity of 5600 MW could add nearly 10,000 jobs, and also generate about 36,000 person years of construction and manufacturing business.
10. ‘‘Biomass 2’’ calculation is based on the average of Kammen (2004) biomass numbers, which are based upon REPP 2001 feedstock processing estimates and assuming that the energy facility would be similar to a coal-fired power plant.
11. Kenley (2004) nuclear data based on employment numbers from figure 6 and for 41 plants deployed by 2024 (p. 15). Job numbers are assumed to capture all manufacturing and construction jobs, but an adjustment was made to O&M data to capture all O&M jobs over lifetime of facilities.
12. The CALPIRG 2002 technologies (Geothermal, Landfill/Digester Gas, and Wind) are taken from Table 2 of the report, based on data from the California Energy Commission from an Oak Ridge National Laboratory I/O model. CALPIRG natural gas data is taken from the analytical analysis on page 15 of report.
13. EPRI (2001) numbers are taken directly from Table C-3 of report for construction and O&M employees for wind, geothermal, biomass, landfill gas/biogas, solar thermal, solar PV, and small hydro.
14. REPP (2001) coal data based on analytical analysis from Appendix B of report for coal plant components and on-site activities, coal plant operations and maintenance, and coal mining and transportation.

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