Fuel Prices, Emission Standards, and Generation Costs for Coal vs Natural Gas Power Plants

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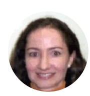

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Employment trends in the U.S. Electricity Sector, 2008–2012

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HIGHLIGHTS

- We examine shifts in the U.S. electricity industry from 2008–2012 by sector.
- We use an economic input–output model to estimate direct and indirect jobs.
- We conducted an analytical, county level geospatial analysis using ArcGIS.
- The coal sector suffered significant job losses, mainly in traditional coal regions.
- Those losses were offset by gains, but typically not in the same geographic areas.

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ABSTRACT

Between 2008–2012, electricity generated (GWh) from coal, the longtime dominant fuel for electric power in the US, declined 24%, while electricity generated from natural gas, wind and solar grew by 39%, 154%, and 400%, respectively. These shifts had major effects on domestic employment in those sectors of the coal, natural gas, wind and solar industries involved in operations and maintenance (O&M) activities for electricity generation. Using an economic input–output model, we estimate that the coal industry lost more than 49,000 jobs (12%) nationally over the five-year period, while in the natural gas, solar, and wind industries, employment increased by nearly 175,000 jobs (21%). We also combine published ratios for jobs per unit of fuel production and per megawatt of power plant capacity with site-specific data on fuel production and power plant retirements, additions and capacity changes to estimate and map direct job changes at the county level. The maps show that job increases in the natural gas, solar and wind industries generally did not occur where there were significant job losses in the coal industry, particularly in West Virginia and Kentucky.

1. Introduction

Through the summer of 2007, total demand for electricity in the United States (U.S.) was growing. The 2008–2009 recession then beset the country, and electricity demand underwent a significant decline, failing to return to pre-2008 levels until 2011 (US EIA, 2014a). Electricity demand since then has been relatively flat, in part because of the following ongoing shifts in the U.S. electric power industry that began between 2008–2012:

- Even though it maintained its historical place as the number one source of fuel for electricity generation, coal experienced a 24% (GW h) decline in use (US EIA., 2014a). Construction of new coal plants was effectively halted, 5.2 GW or 1.5% of U.S. coal plant capacity was retired, and another 60 GW or 18% of capacity was slated for retirement by 2020 (US EIA, 2013a, 2013b).
- Electricity generated using natural gas, on the other hand, grew by ~40% (GW h), and captured a 30% share of U.S. electricity generation by the end of 2012. At the same time, U.S. natural gas plant capacity climbed by 46.6 GW or 9%, and more natural gas plants were used to provide base load power, displacing coal capacity traditionally used for this purpose (US EIA, 2013b).
- New wind generating capacity grew even faster than new natural gas capacity, exceeding the latter in 2012 to total 59 GW (US EIA, 2013b). Electricity generation with wind also rose substantially, increasing by 154% (or 85,459 GW h).
- And despite remaining one of the most expensive forms of electricity generation, new solar generating capacity grew fastest of all, expanding 491% over the period to 3.2 GW (US EIA, 2013b). Electricity generated from solar also rose,

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increasing 400% or 3463 GWh to achieve a 3.5% share of the total U.S. electricity produced in 2012.

The reasons for these ongoing shifts are varied and complex. One driver has been changes in fuel costs. Coal prices rose through 2014 due to higher costs associated with mining deeper for subsurface coal (US EIA, 2013c). At the same time, large-scale deployment of directional drilling and fracking made it economical to produce unconventional shale gas reserves, raising supplies and dropping the price of natural gas through the end of 2012 (US EIA, 2014c).

Environmental Protection Agency (EPA) regulations governing power plant emissions were a second driver for the shifts (US EPA, 2013d; US EPA, 2014d). Although federal climate change legislation was effectively shelved in 2009, tighter EPA regulations on emissions, have threatened fossil fuel plant economics, especially coal plants, which emit more of these pollutants than natural gas plants (Pratson et al., 2013). Along with the fuel price changes, the current regulatory regime has chilled investment in not only building new coal plants, but also upgrading existing ones to meet emission standards, contributing to the large number of coal plant retirements (Institute for Energy Research, 2012).

Finally, a third cause for the shifts in the electric power industry has been the combination of government incentives plus innovations in private financing for electricity generation from renewable energy, principally wind and solar (Database of State Incentives for Renewable & Efficiency, 2014a, 2014b). At the start of The Great Recession, the federal government enacted a major stimulus plan, much of which focused on facilitating the development and deployment of "green" energy (US DOE, 2013). The production tax credit for renewable energy was also extended, bolstering investment in large-scale wind and solar plants (Database of State Incentives for Renewable & Efficiency, 2014c). And as expansion of state renewable portfolio standards lowered the cost of smaller-scale investment in solar, the growth of third party power production agreements made it possible for homeowners to shoulder little if any upfront capital costs in return for solar energy at fixed, competitive electricity rates (US EPA, 2014d).

In contrast to their causes, the transitions that the U.S. electricity industry has been experiencing appear to have had a clear impact on jobs not only within the industry, but also in supporting industries. Job losses in the coal industry have received considerable press, as has the growing demand for workers in the oil and gas industry, and to a lesser extent, in renewable energy. Such job losses and gains are closely followed because they represent an important component of high-paying jobs in the U.S., are a proxy for growth or contraction of major U.S. energy industries, reflect associated growth or contraction of indirect jobs in other industries that support and/or rely on these energy industries, indicate the economic health of local economies where these industries have a dominant effect on direct and indirect employment, and are politically important to representatives of these areas elected to protect and improve economic well-being (Conca, 2012).

Among the most reliable job estimates are those produced by federal government agencies, such as the U.S. Energy Information Administration (EIA), Bureau of Labor and Statistics (BLS), and U.S. Mine Safety and Health Administration (MSHA). These employment figures are published on a monthly, quarterly, and/or annual basis, based on forms and surveys collected by each agency. Being aggregate, however, these numbers do not always partition changes among those sectors in various industries that are part of the electric power "supply chain", i.e. provide goods and/or services that contribute to the production of electricity. Consequently, the numbers fail to elucidate how the ongoing shifts in the electric power industry have affected overall employment across the industry, including indirect jobs.

This paper focuses on O&M jobs, including mining and extraction activities, transportation and distribution, plant workers, and maintenance and repair employment. We exclude construction, installation, and manufacturing (CIM) jobs, because the first two job types are typically short term and project based and thus nomadic in nature, while the third type of job can be non-domestic. In fact, much of the wind and solar technology installed in the U.S. has been manufactured overseas, particularly in China (Mathews and Tan, 2014). Another reason for why we focus on O&M jobs is because they are more numerous over the lifetime of power plants. For fossil fuel plants, O&M accounts for 3–25 times more jobs than CIM, thereby encompassing the bulk of permanent jobs in the coal and natural gas industries (Wei et al., 2010). For the wind energy industry, the number of O&M vs. CIM jobs is roughly the same. The solar industry is somewhat different. For solar thermal there are 1.5–2.5 more O&M workers than CIM, while for solar photovoltaic (PV) there are 1.5–3.5 more workers in CIM than in O&M (Wei et al., 2010). These ratios could be much different, and total domestic jobs in the solar and wind industries could be much higher, if not for significant outsourcing of renewable jobs to China (United Nations Environment Programme, 2010).

The goals of this paper are to (US EIA., 2014a) estimate, at a national level, the increases and decreases in direct and indirect employment associated with electricity generation that occurred in the coal, natural gas, wind, and solar industries between 2008 and 2012, and (US EIA, 2013a) map the changes in direct employment among these four industries at the county level. We use the Economic Input Output-Life Cycle Assessment (EIO-LCA) Model to estimate that on a national level operational hires in the natural gas, solar, and wind industries more than offset O&M layoffs in the coal industry (Carnegie Mellon University, 2009a). However, these job changes were not uniformly distributed about the U.S., as we show in maps of generating-plant additions and retirements, rail routes, and new gas wells coupled with county level job estimates derived from these activities.

2. Previous work

Attempts to constrain job changes in the coal, natural gas, and renewable energy industries have been carried out by many others. Bacon and Kojima (2011) detail the complexities of estimating energy sector employment, including the pros and cons of surveys, plant data, economic input–output models, and combinations of the three. They find that one of the most important steps in calculating energy jobs is separating long-term jobs from short-term construction and installation jobs. They also stress the importance of including indirect jobs, which are related to direct jobs by a multiplier that tends to be ≥ 2 for fossil fuel industries and between 4–11 for renewable energy (Bacon and Kojima, 2011).

Singh and Fehrs (2001) presented a detailed analysis of jobs in the electric power industry on a per-megawatt (MW) basis for coal and renewable energy using EIA, BLS, NREL, DOE and other data that spanned multiple sectors of each industry. The study did not include indirect job estimates, however, and according to Wei et al. (2010) is no longer accurate given the significant changes in energy efficiency and technology that have occurred since the study's publication. A similar problem exists with the modeling results reported on by Rose and Wei (2006). They estimated that the U.S. coal industry would employ between 400,000 and 9 million direct and indirect employees in 2015. The range is large because the authors' estimates included scenarios involving both expensive and cheap fuel alternatives to coal as well as 0%, 33%, and 66% displacement of coal generation by other types of power plants.

The study, however, was also based on energy trends and conditions in 2005, which ended up being quite different from current conditions. As result, it is the low-end job estimates of Rose and Wei (2006) that appear to be the most accurate heading into 2015.

Weber (2012) analyzed the impact of shale gas production on employment in the Western and Central U.S. using reserve, production, population, household income, and poverty data for boom and non-boom counties. He found that county-level employment projections were often inflated if derived from economic input–output models that were designed for use at the regional-to-national scale and/or included transitory (non-local, specialized) workers. For example, Weber estimated that at the county level 2.35 jobs were created per million dollars of natural gas production, which was lower than the figures of 11.75 published by the Center for Business and Economic Research (CBER) (2008) at the University of Arkansas and 47.46 arrived at by Considine et al. (2011).

Accurately estimating jobs in renewable energy has also proved tricky. Lehr et al. (2012) used macroeconomic data, input–output data based on the use and cost of renewable energy technology, and extensive industry surveys to assess capital costs, operations and maintenance (O&M) costs, and job creation associated with renewable energy growth in Germany. They concluded that deployment of renewable energy leads to significant employment, and creates more indirect jobs than fossil fuel energy. However, Lambert and Silva (2012) found that quantifying jobs created by renewable energy is difficult and that the results are often a source of debate. They do find though that a combination of employment estimate techniques is often best, emphasizing input–output (I–O) models and analytical methods. They also note that I–O models tend to give the best results when used at a national or international level, because at these larger scales the models generate more accurate indirect job estimates.

The employment picture for the U.S. electric industry is complicated by regional variability. Appalachia, a historically top coal-producing region in the U.S., has seen significant decreases in coal mining. Employment in Kentucky has decreased 33% in the past five years while in West Virginia 13% of coal mining jobs have been lost over the past three years (US Department of Labor – Mine Health and Safety Administration, 2014). Collins et al. (2012) suggest that wind production is better than mountain-top-mining not only for the environment but also for the economy and employment. Little wind capacity has been installed in Appalachia, however, with the majority of additions taking place in the West and Midwest. The same is true for solar, which has undergone the greatest capacity additions in California, Arizona, and Nevada (US EIA, 2014a). And although natural gas extraction is becoming more prevalent in Appalachia, much more new natural gas electric power plant capacity has been added in Pennsylvania and New York (US EIA, 2014a). This also applies to new pipeline capacity, of which only 9.7% has occurred in Appalachia since 2008 (US EIA, 2013e).

Despite the numerous studies of job changes in individual energy sectors, such as coal mining, studies of job changes across the supply chain of an energy industry are rare. Furthermore, to our knowledge none have yet resolved, let alone addressed, the interrelated employment shifts in the U.S. electric industry begun in 2008.

3. Methods

In general, jobs in the energy industry are either manufacturing, construction, and installation jobs or they are operation jobs. The former category is difficult to tabulate. Many of the companies that build and install energy infrastructure (e.g., mining equipment, turbines, plants) also manufacture and construct equipment/infrastructure for other industries (e.g., the chemical, electronics, or metal industries). These companies tend to be situated in one to several locations and move their equipment and/or workers to temporary job sites. And it is not uncommon for some or all of the equipment to be assembled overseas using non-U.S. workers. Consequently, this study focuses on operation jobs. These are local jobs done by U.S. workers that exist for as long as the operation, which can be 20–50 years for a power plant and decades longer for a mine (US Department of Labor–Mine Health and Safety Administration, 2014; US EIA, 2013f, 2013g).

Fig. 1 illustrates the operational jobs addressed in this study. The jobs depicted are in the context of those activities in the electricity supply chain involving the coal, natural gas, solar, and wind industries. We have ignored other industries that contribute to the electricity supply chain, such as nuclear and hydro, because electricity generation from plants associated with these industries was relatively constant from 2008–2012, and we assume that operational jobs associated with the plants were fairly constant as well (US EIA, 2014a). Similarly, we have ignored those sectors of the coal, natural gas, solar and wind industries that lie outside the electric supply chain. For example, we exclude jobs linked to metallurgic coal and coal imports/exports.

Note that while the operational activities of the wind and solar industries in the electricity supply chain are limited to electricity generation. Coal and natural gas activities in the supply chain also include the extraction, processing, and transport of the fuels required to run coal and natural gas plants (Fig. 1). This more extensive involvement of the coal and natural gas industries in the electricity supply chain will be seen to have significant bearing on our results.

Wind and solar also differ from coal and natural gas in terms of how we are able to analyze industry jobs tied to the electricity supply chain at the national level. For coal and natural gas, we estimate the number of direct and indirect jobs in the country for every year between 2008 and 2012 using the publically available Economic Input–Output Life-Cycle Assessment model. The EIO-LCA requires two inputs (Carnegie Mellon University, 2009b). One is the North American Industry Classification System (NAICS) code for each sector in the coal and natural gas industries that contributes to one or more electricity supply chain activities. The other is the dollar value for the total annual economic activity for that sector. Economic activity is based on producer price for a specific NAICS code. For example, if a ton of coal costs $25 to produce and 1-billion tons were produced annually, the economic activity would be $25-billion dollars in the Coal Mining sector despite selling for considerably more money (Carnegie Mellon University, 2009b). The values of economic activity are derived from the input–output benchmark “make table” developed by the Bureau of Economic Analysis (BEA) (Bureau of Economic Analysis, 2014). The EIO-LCA uses this table to trace back the supply chain for each industry sector and assign a fraction of that sector's total production value to every other industry sector in the supply chain that contributed to the production (Carnegie Mellon University, 2009a). Note that we will henceforth refer to these other industry sectors as subsectors.

A challenge in carrying out this type of analysis for industry sectors involved in the electricity supply chain is that in many cases only a fraction of the output from these sectors goes towards electricity generation. For instance, 89% of the coal produced in 2008 by the coal-mining sector was used for generating electricity, while the remainder was consumed by other industries. To properly account for this, we further scale the fractional production values that the EIO-LCA ascribes to a sector by the percentage of the production used in the electricity supply chain. So in the case of coal mining for 2008, we multiplied the fractions of the sector's

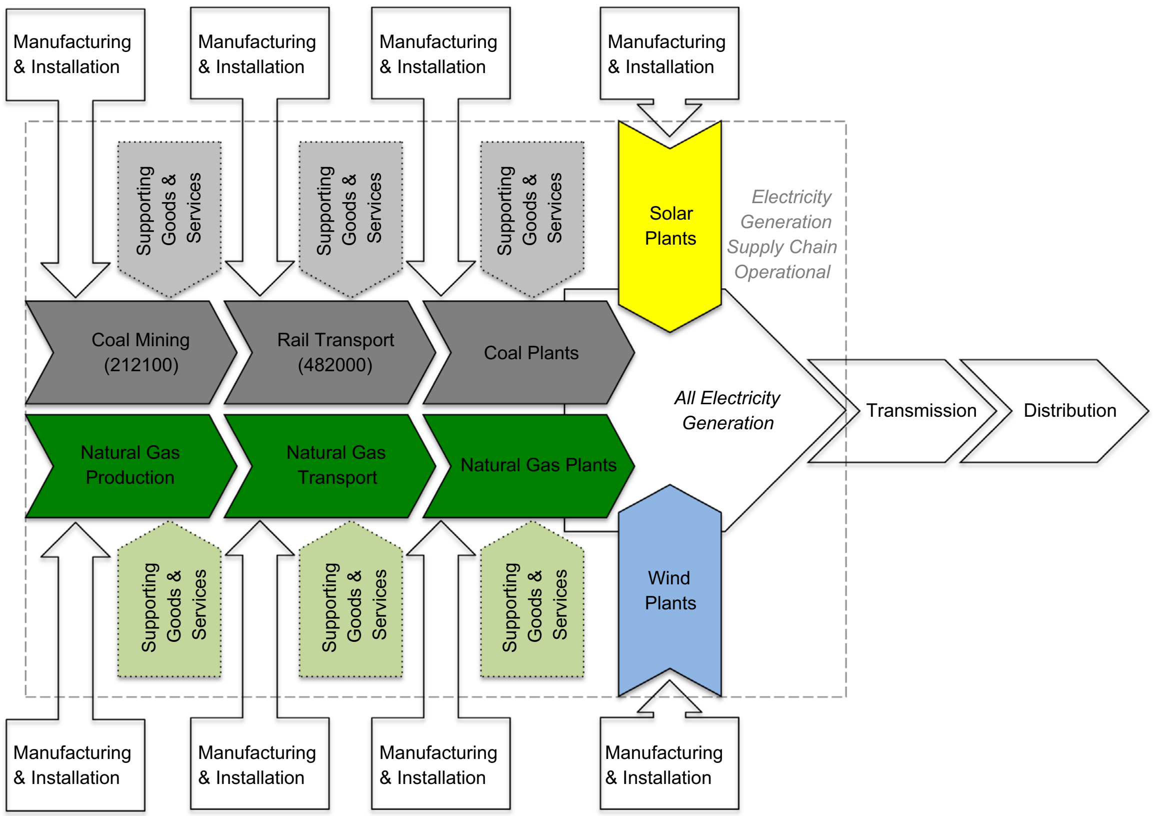

Fig. 1. Schematic of the coal (gray), natural gas (green), wind (blue) and solar (yellow) industry sectors involved in operational activities of the electricity generation supply chain (box with gray-dashed line) analyzed in this study. Other sectors involved in the supply chain inside and outside of operational activities (e.g., manufacturing & installation boxes) and these four industries (e.g., nuclear and hydroelectric, encapsulated under "All Electricity Generation") are not considered (unfilled boxes and arrows). Operational activities include the operation and management of electric power plants and, if the plant type requires fuel to run, the extraction, processing and transport of the fuel to the plant type, which is why the supply chains for the coal and natural gas sectors are longer. NAIC codes used in modeling employment in the coal and natural gas sectors are indicated beneath the sector names. Direct jobs are estimated for all sectors analyzed (filled arrows with solid black lines), while indirect are also estimated for sub-sectors that support each of the coal and natural gas sectors involved in the supply chain (filled arrows with dotted black lines). See text for further details. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 1

Scaling of 2008 economic activity input values for the EIO-LCA model. Inputs to the EIO-LCA are the NAICS code for a sector and its economic activity or total production value in producer price dollars of output. The EIO-LCA uses the NAICS code to correlate the production value with other industry sectors, or sub-sectors, that support the input sector as indicated by the BEA Input–Output Benchmark 2002 make table. The fractions of production values assigned by the EIO-LCA to the sector and its sub-sectors are then further adjusted to properly reflect the proportion of the sector's economic activity that went towards operational electricity generation supply chain activities. These adjustments were done for each of the five years of activity analyzed. The purpose of this table is to illustrate our approach; hence it only shows the adjustments made to calculate inputs for 2008. Also, note that the input values column was used to calculate jobs per million dollars, as discussed in Section 5.

Sources: (US Department of Labor – Mine Health and Safety Administration, 2014; American Association of Railroads, 2014; US EIA, 2013o, 2013p, 2013q).

Sector	BEA benchmark value ($M)	2002–2008 adjustment	Power adjustments	Input value ($M)
Coal mining	11196.2	1.07 times more coal produced	89% of coal used for power generation	10663
Support activities for coal mining	1299.8	12.5% fewer coal based production employment	89% of coal used for power generation	848.3
Rail transportation	22693	6.5% fewer coal rail shipments	89% of coal used for power generation	7573.7
Power generation-coal	73723.2	1.13 times more power generated	30.26% of power generated from coal	25900.6
Oil & gas well drilling	6756	1.86 times more wells installed	46% of wells produced gas for power generation	5777.2
Natural gas extraction	51379.4	0.5% more oil and gas production	22% of production is natural gas used for power generation	11350.5
Support activities for oil & gas operations	8958.2	1.83 times more natural gas production employment	46% of jobs linked to natural gas production for power generation	7524.2
Pipeline transportation	16668	1.0055 times more oil and gas transport via pipeline	22% of production is natural gas used for power generation	3682.2
Natural gas distribution	55330.2	1.07 times more natural gas produced	31% of natural gas used for power generation	18247.9
Power generation-natural gas	73723.2	1.13 times more power generation	43% of power generation from natural gas	35938

production value credited directly to the sector and indirectly to its subsectors (e.g., mining machinery construction) by 89% (US EIA, 2013h). Finally, we arrive at "adjusted" job estimates by using the scaled employee-compensation component of the EIO-LCA output for these direct and indirect values. We divide these compensations by published average salaries for the sector and its subsectors to estimate the number of direct and indirect jobs, respectively (Bureau of Labor and Statistics, 2014). A complete list of the values used in these calculations, their sources, and example calculations for 2012 are given in Table 1 and Appendix A.

The EIO-LCA relies on the most recent input–output benchmark make table published by the BEA, which is for 2002 (Bureau of Labor and Statistics, 2014). Rather than convert the prices of coal and natural gas between 2008 and 2012 into 2002 dollars, we simply scaled the 2002 production values for these fuels by the percent change in their production amounts between 2008 and 2012. Using coal as an example again, production in 2012 represented 93% of coal production in 2002, so we decreased the 2002 production value for coal by 7% to arrive at a 2012 value (US EIA, 2013h). The changes in production amounts used for the other sectors in this additional step are included in Table 1. Note that for simplicity all monetary values are kept in 2002 dollars.

The EIO-LCA approach for estimating jobs in the coal and natural gas industries could not be used for the wind and solar industries because sector codes for these industries were not included in NAICS until 2010. Instead, we rely on national level estimates of wind and solar employment published for 2008–2012 by the American Wind Energy Association and the Solar Foundation (The Solar Foundation, 2013; American Wind Energy Association, 2013). The values reported by these organizations are for total jobs only; there is no direct vs. indirect job breakdown. The organizations do, however, provide total employment in each sector of the wind and solar industries (Fig. 1).

At the more granular county level, we used job numbers per MW of generator capacity established by Wei et al. (2010), Carley et al. (2011), and Rutovitz and Harris (2012) to estimate employment changes in electric power plant operations. These authors have also determined job numbers per MWh of energy generated, but we use the more conservative capacity-based figures because a certain number of employees are needed to maintain and operate an electric plant of a given capacity regardless of the plant's energy output, and it is these long-term jobs that our analysis is focusing on. Plant data comes from the EIA, including the types and nameplate capacities of the generators at the plant, plant location (latitude and longitude), and plant capacity additions and retirements (US EIA, 2013i). Multiplying the job numbers per MW of capacity with the generator-level capacity data for 2008–2012, we estimate annual O&M employment in every county containing one or more coal, natural gas, wind and/or solar generators. Minimum, maximum, and average net employment change were then calculated and mapped with ESRI ArcGIS for each generator type.

A similar approach was used to estimate coal-mining jobs at the county level. Changes in county-level coal production between 2008 and 2012 were multiplied with 10-yr averages for miners per ton of coal to arrive at the number of coal miners per county (US EIA, 2013h). A 10-yr average was used instead of an annual average because the average annual miners per ton of coal increase over the period of our study (and overall from the 1990s to present). In addition, the coefficient of variation of the data (i.e., the standard deviation of the data divided by its mean) is 0.1, suggesting little annual variation. Therefore, the 10-yr average both encompasses the time frame of our study and yields a conservative, yet accurate, estimate of jobs. Employment in natural gas production, on the other hand, was not analyzed because many jobs in this sector are filled by transient workers (Hunt and Gearino, 2014; Cunningham et al., 2012).

Finally, additional data for the coal industry allowed us to analyze coal transport routes and coal mines affected by coal plant retirements identified by the EIA (Carley et al., 2011). The additional data included the EIA coal transportation rate database (US EIA, 2011), and the US Department of Transportation (US DOT) Freight Analysis Framework 3 (FAF3) networks (US DOT – Freight Analysis Framework 3). We used the EIA plant and coal transportation data sets to determine (US EIA., 2014a) the reduction in tons of coal used by generators being retired at power plants, and (US EIA, 2013a) the mine(s) that had been providing that coal. Total reductions in coal demand for each mine were then determined by summing the former coal use among generators at a plant, and then adding up these sums for all plants that had received their coal from the mine. This information was used with the EIA coal transportation database and the FAF3 freight networks in the ESRI ArcMap Geographic Information System to map the reduction in coal tonnage transported along each U.S. railroad segment. Coal transport via highway, waterway, and other methods was found to be relatively minor ($<25\%$) by comparison, and, notably difficult to estimate (US EIA, 2013j; Singh and Fehrs, 2001). The map depicts the impact of current coal plant retirements on the coal industry supply chain from mine to power plants.

4. Results

4.1. Employment Changes at the national level

Our EIO-LCA estimates of national employment in the coal and natural gas industries cannot be directly compared to estimates published by others because ours are for jobs in the coal and natural gas sectors that participate in electricity supply chain activities, while others' estimates are for the coal and natural gas industries as a whole (i.e. all sectors in these industries). Our estimates of direct employment in coal mining and natural gas production, however, can at least be indirectly compared with others' estimates by assuming that employment in these sectors scales linearly with production. For example, we stated previously that 89% of the coal mined in 2008 was used for domestic generation of electricity. Thus increasing our estimate of 85,567 jobs by roughly 11% to 94,310 yields a job number that we can compare to BLS, EIA, and MSHA estimates for coal mining employment that year (US Department of Labor – Mine Health and Safety Administration, 2014; Carnegie Mellon University, 2009b; Bureau of Labor and Statistics, 2014). This comparison, along with the same type of comparisons for 2009–2012, are shown in Fig. 2a, while the comparison for natural gas production is shown in Fig. 2b.

It is important to note three things about Fig. 2. First, our estimates include only electricity generation specific jobs, as noted above. Therefore, our values were adjusted based on the percentage of electricity value chain O&M jobs vs total jobs in these industries in order to directly compare to the other estimates. Second, we only have BLS estimates to compare our values to in Fig. 2b. And third, the assumptions that underlie how the BLS, EIA, and MSHA, collect job data and estimate employment likely differ from our approach using the EIO-LCA model. These presumed differences could lead to increased variability among results and are a reason for caution when comparing them to each other. Still, in comparing Fig. 2a and b, our direct estimates are within 14% of the other estimates with an average difference of 6.5%, indicating that our approach yields similar results.

Our estimates for the coal industry project that the coal mining sector lost jobs at a rate of $\sim$5% per year between 2008 and 2012, and that employment trended downward in all industry sectors involved in the coal supply chain (Fig. 3a). The 'coal mining support activities' sector experienced the smallest employment decrease at roughly 3%. Jobs in this subsector include mine site preparation, removing overburden, constructing mine shafts, mine draining, and other activities, all crucial for coal operations and production, regardless of the amount of coal being produced (NAICS Association, 2010a). The downward trend in employment projection for the rest of the coal industry stems from a 16.3%

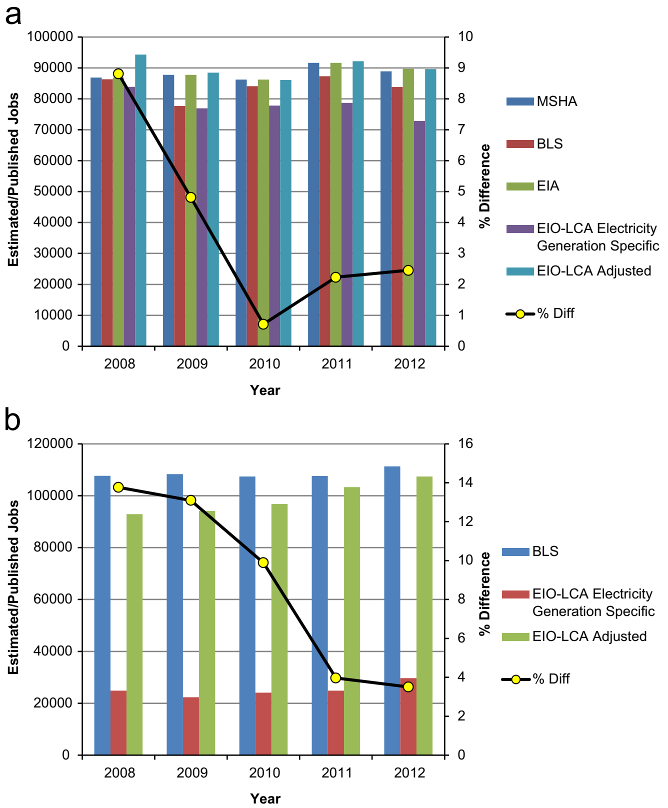

Fig. 2. Extrapolation of EIO-LCA results for direct jobs in the electricity supply chain of (a) coal mining and (b) natural gas distribution NAICS sectors to all job numbers in these sectors as compared to the same type of estimates by the BLS (coal and natural gas) and the MSHA (coal only). Although the comparison is indirect (see text for details), all estimates are within 14% of each other, indicating that the job estimates produced by the EIO-LCA approach are reasonable. These specific NAICS sectors were chosen for comparison because they could be compared most directly to published (BLS, MSHA, etc.) data.

decrease in the amount of coal used for electricity generation (US EIA, 2014a). This in turn is due to an 11% decrease in coal-fired electricity generation and the previously mentioned 5 GW decrease in installed coal generating capacity (US EIA, 2014a, 2013a). We estimate that the coal industry lost 49,534 jobs between 2008 and 2012, which when combined with $3.76B (2002$) of lost production for the industry equates to direct job losses of 6.58 direct jobs per million dollars (2002$) and 13.18 total (i.e., direct+indirect) jobs per million dollars (2002$) over that time span.

The EIO-LCA employment estimates for natural gas on the other hand trend upward in every sector of the industry that is linked to electricity-supply-chain activities except well drilling (Fig. 3b). Support for the latter finding is seen in the decline in the percentage of U.S. rigs drilling for natural gas, which dropped from 81.7% in 2008 to 24.2% in 2012 (Baker Hughes, 2014). Note that the price of natural gas fell from $8.73/MMBtu to $2.90/MMBtu over the same time period (Pratson et al., 2013). In contrast, the natural gas sector where jobs are projected to have increased the most is support activities, which includes building well foundations, rock core drilling, preparation of drilling sites, well logging, and other activities (NAICS Association, 2010b). Combined, the two sector changes suggest that the upstream part of the natural gas industry is becoming more efficient; requiring less manpower to drill more wells in addition to further developing and improving the performance of existing wells as the profit margins on natural gas production narrowed (Eaton, 2013; US EIA, 2013k).

The low-cost of natural gas fueled a rise of over 30% in its use in electricity generation between 2008 and 2012 (US EIA, 2014b), leading to an estimated increase of 94,702 jobs in the natural gas industry over the four-year period. This estimate is almost two times (191%) larger than our estimate for job losses in the coal industry for the same time interval. The value of production from the industry increased $11.2B, which when combined with the job increases suggests a net gain in the industry of 3.53 direct jobs per million dollars (2002$) and 8.43 total jobs per million dollars (2002$).

The reported values for employment in the wind and solar industries imply similar growth. Published estimates place total domestic jobs in both industries in 2012 at 199,016, which is an increase of 79,016 jobs over that in the year 2008 (The Solar Foundation, 2013; American Wind Energy Association, 2013). However, that increase still offset 159% of the job losses that we estimate occurred in the coal industry (Fig. 4). Thus when our job estimates for all four industries (coal, natural gas, wind and solar) are combined, we project a net increase of 124,184 jobs between 2008 and 2012. An important factor in this increase is the higher job multipliers (i.e., indirect to direct job ratios) for the natural gas, wind and solar industries as compared to the coal industry. Our EIO-LCA results yield a multiplier of 1.9 indirect jobs per direct job in the coal industry, which compares well to previous estimates by Peach and Starbuck (2009) and Thompson et al. (2001) of 1.54–2.12 and 2.25, respectively. For natural gas, we estimate the multiplier to be 3.1, which is 60% higher than that for coal. This value is similar to values reported by the Center for Economic Development and Business Research (2012) and Cohen (2012), which report natural gas industry multipliers of 3.28 and 3, respectively. Although we are unable to also estimate wind and solar multipliers, studies suggest that the solar job multiplier may be more than 5 times that of coal, and that the wind energy multiplier could be another 50% higher (Wei et al., 2010). As noted previously, however, the definition of a job in the renewable energy industries is still being debated, so these much higher multipliers may be inflated (Bureau of Labor and Statistics, 2013).

4.2. *Employment changes at the county level*

As our estimates of county level employment depend on either jobs per megawatt of generator capacity or jobs per unit of fuel production, we begin by mapping the changes in power plants, fuel production, and fuel transport that occurred between 2008 and 2012. Fig. 5 presents maps of electric power plant retirements, additions, and capacity changes. While there were a few coal plant additions in the Midwest and Gulf of Mexico regions, coal plant retirements were much more numerous (Fig. 5a) with the majority occurring east of the Mississippi River, particularly in the post-industrial regions of the Northeast and Midwest as well as in portions of the Southeast. Despite the greater number of plant closures, however, the overall decrease in coal-plant generating capacity was only 1.5%. This is in line with previous reporting that the majority of closures were relatively small plants (avg. capacity of 112 MW). The few additions on the other hand tended to be larger plants (avg. capacity of 260 MW) (US EIA, 2013b).

The broader impact of the coal plant retirements on the other coal sectors involved in electric supply chain activities is mapped out in Figs. 6 and 7. Fig. 6 ties the coal plant to railroad routes and mines that supplied the plants. Most of the retired plants received their coal from either the Powder River Basin or Appalachian mines, with the majority of this coal having been transported by rail across the Midwest and Appalachia. Although the impact of the latter on rail transportation jobs is difficult to quantify, all four of the major rail carriers (Burlington Northern and Santa Fe, CSX, Norfolk Southern, and Union Pacific) experienced coal-shipment decreases of 8–31% between 2008 and 2012, with CSX being hit

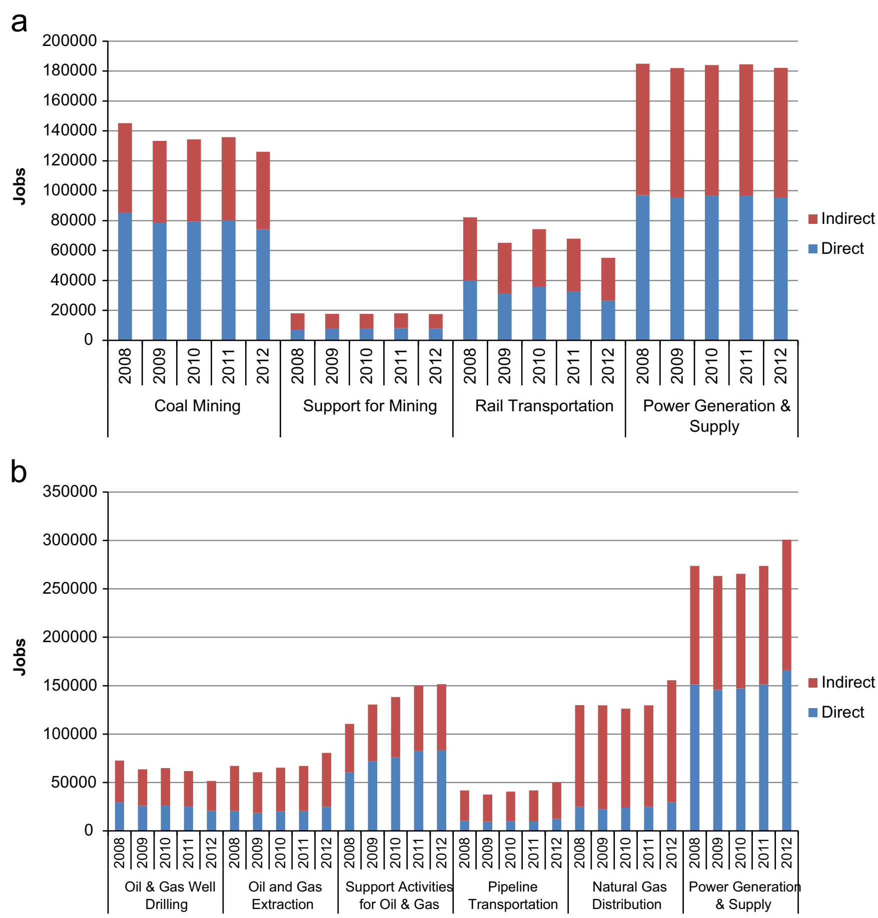

Fig. 3. EIO-LCA model results for direct, indirect and total job number estimates in the electricity supply chain (a) coal and (b) natural gas industry sectors for each year between 2008–2012. Estimates indicate the coal industry sectors (a) lost a total 49,534 jobs, at a rate of ~5% annually. In contrast, the natural gas industry sectors (b) added 94,702 jobs over the same 5-y period, offsetting 191% of the total coal job losses.

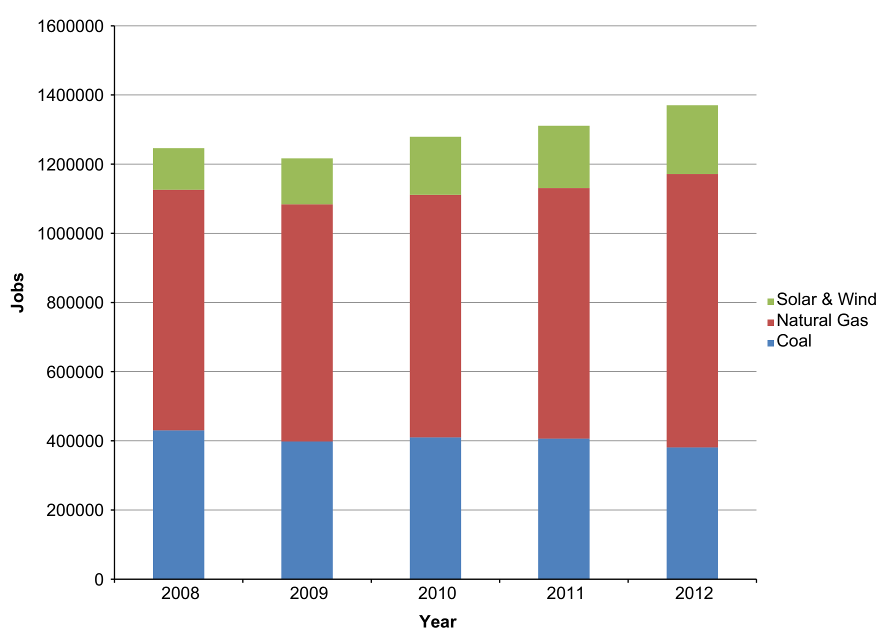

Fig. 4. Total employment (direct + indirect job) estimates from 2008–2012 for each industry analyzed. Of the four industries, only the coal industry experienced job losses. Natural gas added the most jobs. Solar and wind jobs were grouped together and account for an increase of roughly 79,000 jobs over the timer frame analyzed. Combining the sectors yields a net increase of 124,184 jobs over the 5-yr period.

the hardest (Burlington Northern Santa Fe Railway Company, 2013; CSX Corporation Inc, 2014; Norfolk Southern Corp, 2013; Union Pacific, 2014). CSX operates east of the Mississippi only and, along with Norfolk Southern, is responsible for the majority of coal rail shipments in Appalachia.

Independent support for the declines projected in Fig. 6 is seen

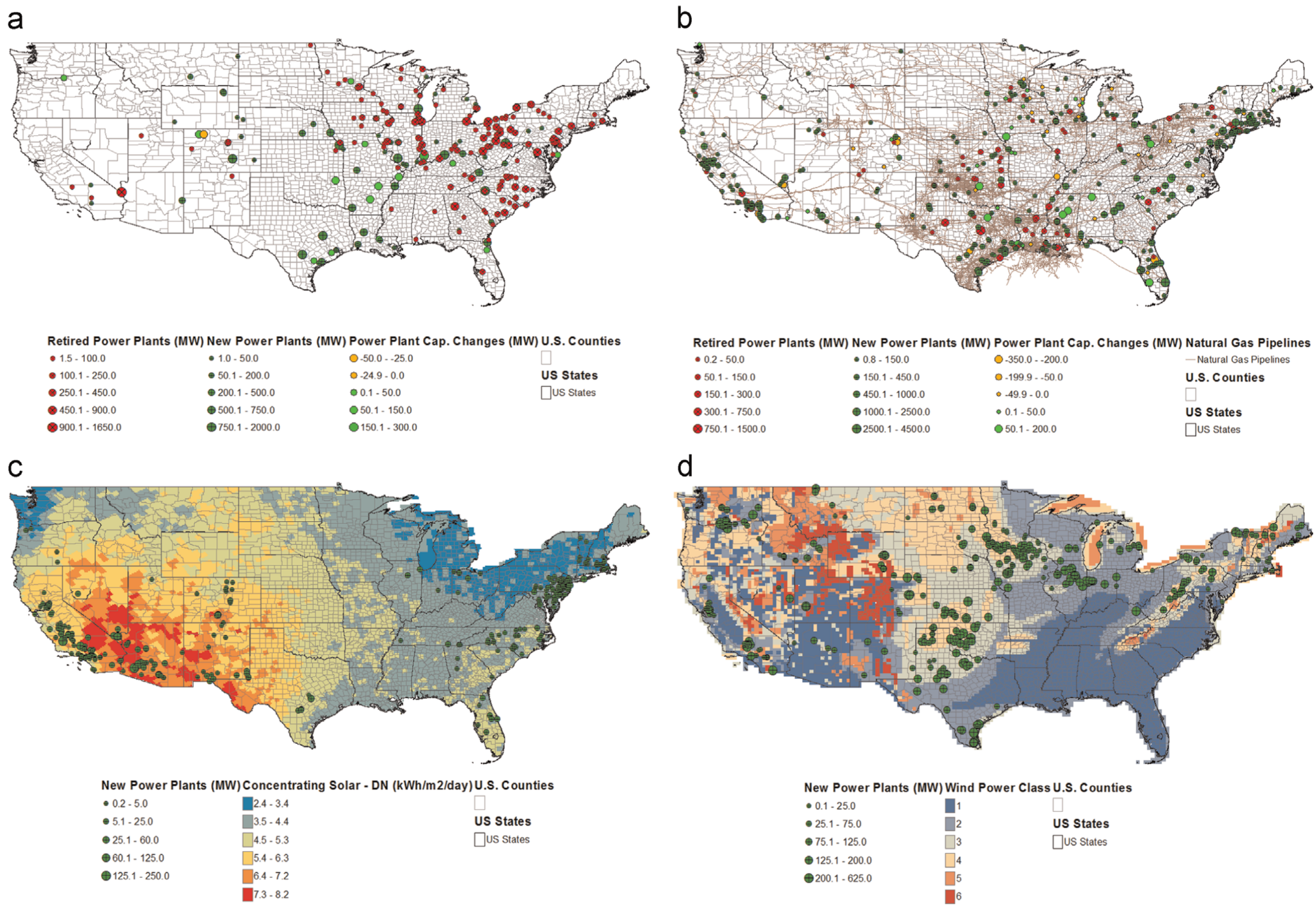

Fig. 5. Maps of (a) coal, (b) natural gas, (c) solar, and (d) wind power plant retirements, additions, and capacity changes (due to partial closures/fuel switches). The capacity changes were analyzed at the generator level and summed to yield the mapped changes at the plant level. Retired plants are noted by red-filled ⊗ symbols. Additions are noted by green-filled ⊕. Plants where capacity was reduced are noted with orange-filled circles while those where capacity was increased are indicated by green-filled circles. All symbols are scaled based on current generating capacity (MW). Plant data for (a)–(d) are from the EIA Electric Power Dataset (US EIA, 2013a, 2013b). Underlying resource potential in plant maps for solar (c) and wind (d) are from (National Renewable Energy Laboratory (NREL), 2014a, 2014b). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

in county-level changes in coal production derived from EIA data (US EIA, 2013h) (Fig. 7a). Coal production decreased most in the Powder River Basin and Appalachia despite increased coal exports over the same time frame (US EIA, 2014e). And although the largest decrease in tonnage of coal production occurred in the Powder River Basin, the greatest percentage decline in coal production occurred in Appalachia, particularly in Kentucky and West Virginia.

A contrasting picture is seen for natural gas. More natural gas plants were added than retired (Figs. 5b and 7 b), though the number of closures was significant and concentrated in the Gulf of Mexico and the Midwest. The plant additions largely occurred along the East Coast, Gulf of Mexico, Midwest, and California, with many being located near major interstate pipelines, such as the Transco pipeline, which transports gas from Texas to the Mid-Atlantic and Northeastern states (Williams Company, 2014).

Changes in natural gas production between 2008 and 2012 varied significantly at the county level. Production decreased in many counties, yet overall production increased by 3,899,007 thousand cubic feet (MCF) (US EIA, 2014f; US Department of Agriculture, 2014). The counties where this production increase was greatest are located in Pennsylvania, North Dakota and west Texas.

Turning to renewables, the majority of new solar capacity was in the form of large, central solar and PV plants in the West and Southwest (Fig. 5c). Many photovoltaic capacity additions also occurred in New Jersey and the northeast, presumably because of favorable solar incentives in these states (Database of State Incentives for Renewable & Efficiency, 2014a). No solar plants that produce power for electric utilities were retired over the time frame. The same holds for wind power plants (Fig. 5d). The majority of these additions occurred in high wind areas across the country, with the greatest amount of capacity being installed in the Midwest. In contrast, the Southeast is notable for its lack of new wind installations, presumably because of the lack of good wind resources, and few states with a renewable portfolio standard (RPS), let alone one that offers attractive wind incentives.

Our estimates of county-level employment changes between 2008 and 2012 mirror the changes in power plants and fossil fuel production during this time (Fig. 8). We arrived at the estimates by first solving for low-end and high-end job estimates for each county and energy sector to create a range of job estimates. These two extreme values were then averaged for each sector, and finally summed across sectors to determine a net change in jobs on a county-by-county basis.

Coal employment changes are shown in Fig. 8a, with decreases being the most extensive in Appalachia and in, particular in West Virginia and eastern Kentucky. Campbell County, Wyoming, was also hard hit. Home to the majority of coal production from the Powder River Basin, it lost an estimated 1000 mining jobs between

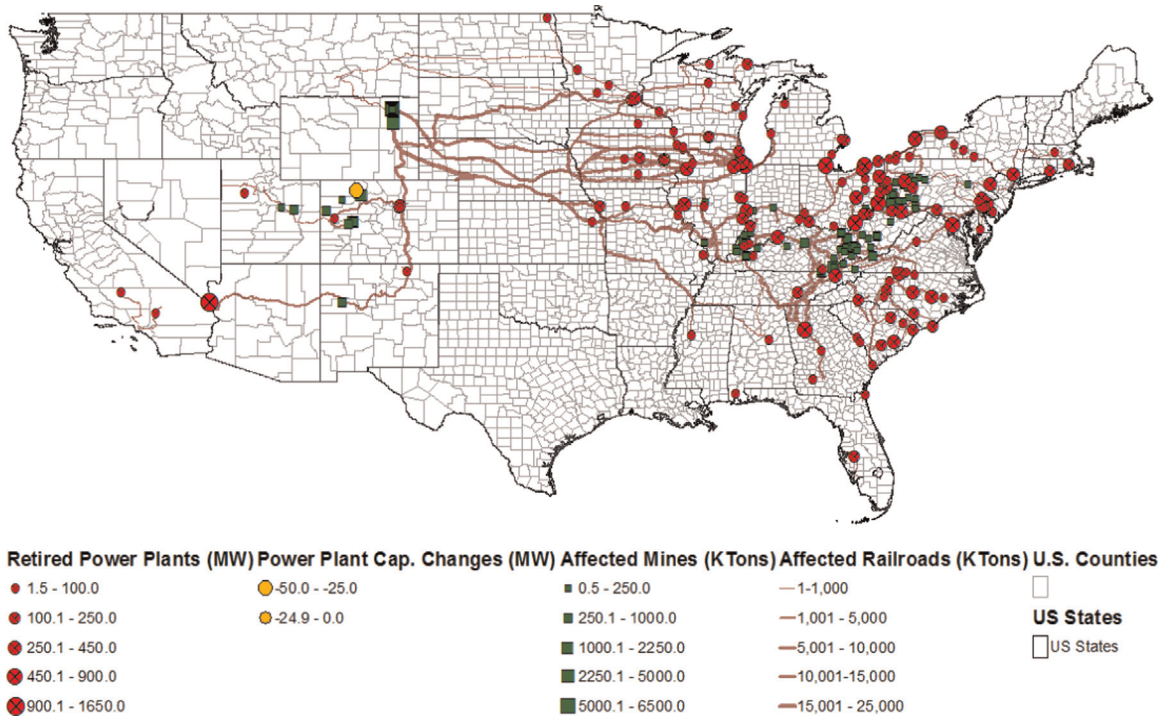

Fig. 6. Estimated impact of partial to full coal-plant retirements on coal mining and rail transport. Full and partial coal plant capacity retirements are indicated by red and orange circles, respectively, with the circle size being scaled by the capacity of the plant (MW). Maroon lines are the rail routes by which coal is transported from mine to plant, with the width of these lines increasing with decrease in tonnage of coal moved. Mines projected to be affected by partial to full plant closures are indicated by green squares, the size of which increase with the estimated decrease in tonnage produced. Note that the Powder River Basin and Appalachia mines along with the rail routes that lead from them stand out as being the regions that have undergone the greatest decline in activity due to the plant retirements. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

2008 and 2012, the most of any county in the U.S. In Illinois, Missouri, Arkansas, and other states, however, coal industry employment remained strong, with many of the counties where coal is being mined from the Illinois Basin posting moderate increases in jobs.

Our employment estimates for the other industries are limited to jobs associated with changes in natural gas, wind and solar electric generating capacity. Natural gas posted the biggest number of job increases, particularly in regions where there has been significant extraction of shale gas, such as the Northeast in the vicinity of the Marcellus Shale, followed by the Barnett and Eagleford Shales in the Gulf of Mexico, the Permian Shales of Texas and New Mexico, and the Bakken Shales in North Dakota and Montana (Fig. 8b). Other counties, particularly throughout the Midwest and West, continue to add natural gas generating capacity due to proximity, cost of fuel, and presumably cost of meeting impending and proposed federal emissions regulations. Relatedly, O&M job increases associated with solar and wind electricity generation are most significant in states mandating the addition of these types of capacity via renewable portfolio standards (Fig. 8c and d). This includes counties in the west and northeast, where job increases have occurred in both industries, and in counties in the Midwest, where wind resources and wind industry employment dominate over solar. In fact, wind installations created significantly more jobs than solar at the local level, in part because the total capacity of wind additions across the U.S. is much higher during the study period.

The total net change for the jobs we analyzed among all four industries is summarized in Fig. 8e. Based on our use of high and low reported values for jobs per MW of electric generating capacity and jobs per ton/jobs per million cubic feet (MMCF) of fuel production, the overall net job gain ranged from a minimum of 7508 to a maximum of 31,186 jobs with an average gain of 19,437 jobs. The net average was based on 844 (out of 3,007) U.S. counties that experienced changes in local O&M jobs. Of these, 584 counties had gains that averaged an increase of 33 new jobs. Although variable, job gains are projected to have occurred through the Northeast, Southwest, Midwest, and Western U.S. The three regions that suffered the most losses are where coal employment dominates; Appalachia, the Uinta Basin of Utah and Colorado, and parts of the Powder River Basin. Job losses are especially prominent among counties along the coal belt through West Virginia and eastern Kentucky. Neither state has diversified its electric generation portfolio away from coal, and so has not gained much in terms of electric plant O&M jobs. And even though West Virginia added 1000 MMCF/day of new natural gas pipeline transport capacity, it appears that the fuel is being transported out of and/or through the state, rather than being used within it, leading to longer-term job creation elsewhere.

5. Discussion

We have attempted to analyze job changes associated with ongoing transitions in U.S. electricity generation when these transitions first became manifest in 2008–2012. Due to a lack of information, our analysis is admittedly limited, while remaining as comprehensive as possible. The only jobs we estimate are O&M jobs in electricity supply chain activities involving the coal, natural gas, wind and solar industries. Industries involved in other forms of electricity generation (e.g., nuclear, hydro and geothermal) are ignored, mainly due to the lack of significant change in those industries. So too are jobs associated with power plant construction/installation and the manufacturing of power plant components. Furthermore, our analysis of O&M jobs is more detailed for the coal and natural gas industries than for the wind and solar

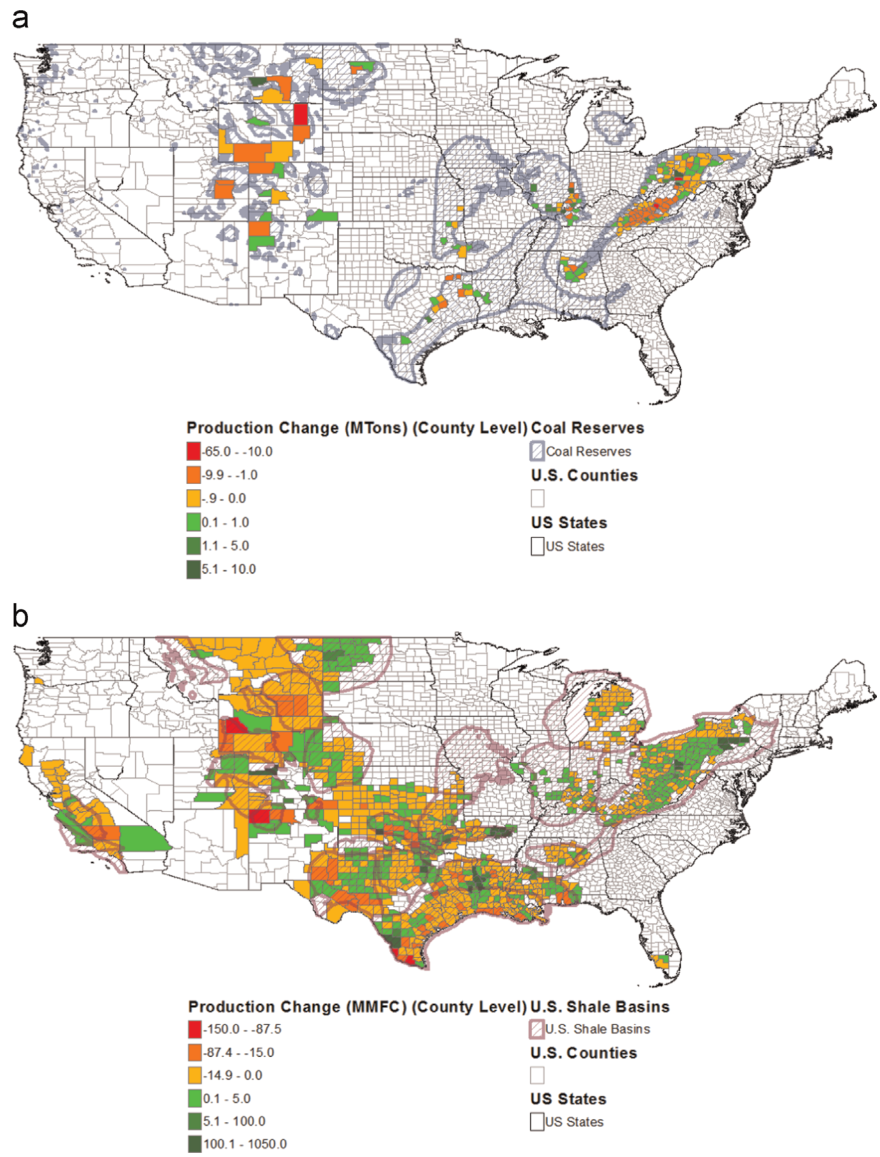

Fig. 7. County level maps of changes in (a) coal and (b) natural gas production between 2008–2012. Superimposed on changes are the boundaries of significant U.S. coal and shale-gas basins. Major coal production decreases are projected to have (a) occurred in the Powder River, Uinta, and Appalachia basins, despite an increase in coal exports from the U.S. over the time period examined. The employment impacts of the major shale gas booms in Pennsylvania and North Dakota stand out (b).

industries, and the range of jobs analyzed is more extensive at the national level than at the county level. In the case of the latter, the only other county-level job number we are able to estimate beyond that related to power plant operation is coal mining. We are not able to estimate county-level jobs say in the natural gas industry associated with exploration and production, nor are we able to even estimate job changes in other sectors of the coal supply chain, such as coal transportation.

Our job estimates also involve considerable and un-quantified uncertainty. All the estimates are based on empirically derived correlations; some of these are direct, like the ratios for job number per unit of sector production, while others are indirect, like the correlations between production values for different sectors used in the EIO-LCA that we then translate into job numbers using published average salaries for the sectors after converting the salaries into 2002 dollars. Furthermore, all of the correlations we rely on were established years earlier and may have either changed or no longer be as statistically significant as they were. And then there is the EIO-LCA, which is based on 2002 data that may not include and/or lump together other sectors of the coal, natural gas, wind and solar industries that also contribute to operational activities in the electricity supply chain (Carnegie Mellon University, 2009).

Despite these shortcomings, we believe that our results are qualitatively correct, and find them to be within the range of estimates published by others (Rose and Wei, 2006; US Department of Labor – Mine Health and Safety Administration, 2014; Bureau of Labor and Statistics, 2014). The industry sectors that we include as major components of electricity supply chain operational activities are the same as those identified by others (Energy Efficiency Exchange, 2013), as is our economic input–output approach at estimating job numbers in the coal and natural gas sectors, which yields estimates that are within ~10% of comparable estimates published by government agencies (Lehr et al., 2012; US DOT – Freight Analysis Framework 3).

Our principal findings are that the changes in electricity generation between 2008 and 2012 led to a nation-wide loss for the coal industry of 49,534 direct and indirect jobs, a 12% decline. These losses, however, were more than offset by a net increase of 125,000 new jobs in the natural gas, solar, and wind industry

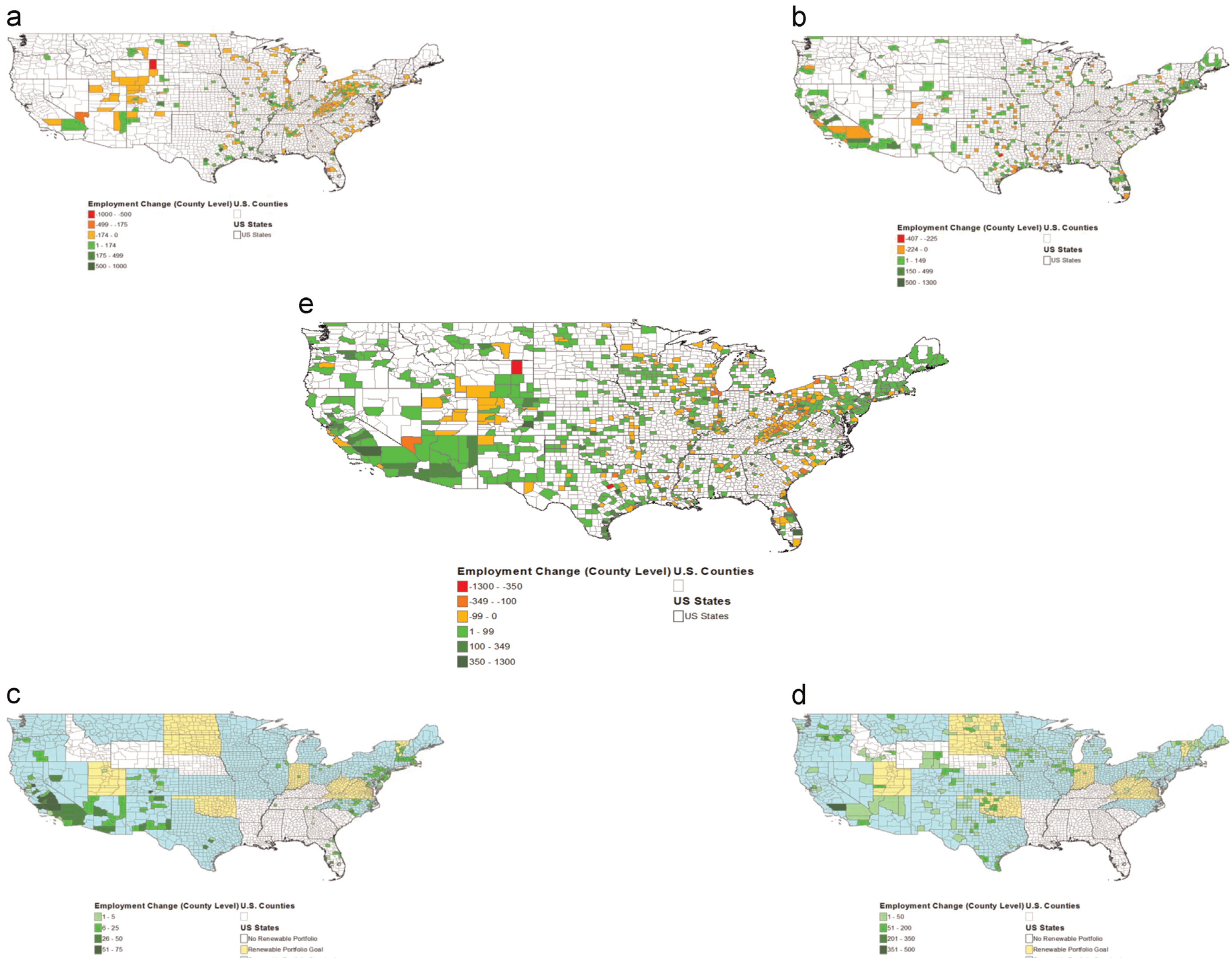

Fig. 8. Estimated changes in county-level employment for the (a) coal, (b) natural gas, (c) solar, (d) wind, and (e) total energy industry sectors analyzed**.** The employment changes for coal (a) include coal mining (jobs/ton) and coal power capacity changes (jobs/MW). Note that the most significant of these changes are in the Appalachia, Uinta, and Powder River Basins. The changes in natural gas (b), solar (c) and wind (d) employment are only for jobs associated with power plant additions and capacity changes. Net change in employment at the county level for all four industry sectors is shown in (e), which projects that natural gas, solar, and wind jobs offset coal job losses overall, and particularly in parts of the northeast, the Carolinas, Midwest, and west. Regions that experienced net job losses include counties in the Appalachia and the Uinta basins, as well as Campbell County, WY, which suffered the most job losses in the country.

sectors supporting electricity operations over the same time frame. Similar offsets occurred in many counties throughout the U.S., but in general counties either experienced a decline in coal industry jobs or an increase in jobs in the other industries. Coal job losses were particularly excessive in portions of Kentucky, West Virginia, Utah and Wyoming.

The near- to moderate-term picture for jobs in the coal industry does not look promising relative to the prospects for jobs in the other industry sectors analyzed. Another 40 GW or more of coal generator capacity is confirmed or projected to be retired by 2020 (Institute for Energy Research, 2012). The states where most of these retirements will occur are Ohio, Virginia, West Virginia, and Texas (Fig. 6). At the same time, new coal generating capacity is projected to account for only 9% of additions through 2016 (US EIA, 2013a), while natural gas, solar, and wind generators are forecasted to represent 65.2%, 18.7%, and 6.7% of the additions, respectively, with minimal retirements (US EIA, 2013l).

The better prospect for jobs in the other industry sectors is also reflected in their respective direct-to-indirect job multipliers. The EIO-LCA yields a multiplier of 1.9 for coal vs. 3.1 for natural gas, with the multipliers published for wind and solar being even higher (Garrett-Peltier, 2010; Engel and Kammen, 2009).

Another informative economic metric to consider is jobs per million dollars of economic activity. This is calculated by dividing our EIO-LCA-based employment estimates for each electricity supply chain sector by the producer price for that sector, i.e. the millions of dollars it cost that sector to produce its goods and/or services (as reported in Table 1). Between 2008 and 2012, coal averaged 5.14 direct and 4.53 indirect jobs per million dollars, while natural gas averaged 3.68 direct and 4.87 indirect jobs per million dollars. These direct and indirect estimates are higher than those calculated by Pollin et al. (2009) and Weber (2012), and lower than those calculated the CBER at the University of Arkansas (2008) and Considine et al. (2011) (Rose and Wei, 2006; Center for Business and Economic Research, 2008). An important reason for the differences is that Pollin et al. based their calculations on million dollars of output value, while Weber, the CBER, and Considine et al. based their calculations on production value or sales. The former is less than the producer price and so yields a lower number of jobs per million dollars, while the latter exceeds the producer price and leads a higher number of jobs per million dollars. Our estimates for direct and indirect jobs per millions of dollars of economic activity fall squarely in the middle of the previous estimates, and when compared to our job multiplier estimates suggest that the coal component of the electricity supply chain creates more jobs per million dollars of economic activity than the natural gas component. From 2008–2012, however, coal's jobs-per-million-dollar ratio fell, whereas that of natural gas remained level, and the ratios for the solar and wind industries exceeded those for the fossil fuel industry by 200% (Pollin et al., 2009).

Further clouding the outlook for coal jobs is the cost competitiveness of coal versus natural gas as a fuel for electricity generation. The natural gas to coal price ratio (on a $/MMBtu basis) is not projected to rise above two until after 2020 (US EIA, 2013m). Pratson et al. (2013) showed that at this low ratio, ~5% of current coal generating capacity is more expensive to run than the lowest-cost natural gas plants operating now. That fraction is projected to rise many times over if emission control systems on older power plants, most of which are coal fired, are upgraded to meet stricter EPA limits on the emission of criteria pollutants, such as SO_2, NO_x, mercury and particulate matter (Pratson et al., 2013). And with the addition of the EPA's new thresholds for CO_2 emissions from power plants, an even greater fraction of coal plants could be forced to close, a concern that is driving a dozen traditional coal states to sue the EPA over the existing, new, and revised thresholds for various power plant emissions (Zajac and Drajem, 2014).

The one bright spot for U.S. coal since 2012 was an ensuing rise in coal exports, particularly to Europe. It seems unlikely though that international demand for U.S. coal will ever fully supplant the decline in domestic demand begun in 2008. Since then, domestic demand has fallen 21%, yet exports continue to represent just 11% or so of production (US EIA, 2013n). Demand from Europe may continue to grow in the near term as the region attempts to reduce its reliance on natural gas from Russia, but if European nations are as committed to reducing CO_2 emissions as they appear to be, it is unlikely that the region's escalating use of coal will continue into the future. Of course demand is also growing in East Asia, especially in China, India and even Japan since the latter closed all 54 of its nuclear reactors following the Fukushima crisis in 2011 (McCurry, 2012). However, the recent 2020 ban on coal powered generation and sales in Beijing may significantly alter China's future coal demand (Chumley, 2014). And the U.S. faces stiff competition from other major coal exporting nations, especially Australia and Indonesia. Both of these countries are located in East Asia and thus are able to supply coal at much lower transport costs. In fact, other coal exporting nations are now starting to challenge U.S. domestic production of coal. As of this writing, U.S. coal imports are on the rise and exports are declining because U.S. coal plant operators are able to buy coal more cheaply from Colombia and Indonesia than Appalachia (Miller and Sweet, 2014; Koch, 2014).

6. Conclusions and policy implications

6.1. Conclusions

Between 2008 and 2012, significant changes in employment occurred in industry sectors that support the operation and management activities of U.S. electric power industry. Our results suggest coal sector lost over 49,000 jobs over the five year period, while natural gas, solar, and wind sectors together gained almost 175,000 jobs. Our county level estimates of job changes, however, suggest increases in the natural gas, solar and wind sectors generally did not occur where there were significant job losses in the coal sector. In particular, West Virginia and Kentucky, along with counties in other states located within major coal basins experienced significant net job losses.

6.2. Policy implications

The primary drivers for the shifts noted in this study, i.e. economic recession, changes in fuel prices, and changes in environmental regulations, are complex and diverse. Of them, the changes in fuel costs are the only driver not directly linked to U.S. federal policy. EPA regulations governing power plant emissions have caused many coal power plants to switch fuel types, generate less electricity, or close altogether because of the significant expenses tied to retrofitting a plant with emissions control technologies. In addition, companies in the renewable energy sectors received government financial incentives in the form of stimulus funding and tax credits.

Even with these current trends in the electricity industry, it is anticipated that coal will continue to fuel at least 41% of U.S. electricity generation through 2020 (US EIA, 2014g). Consequently, there will still be a lot of jobs in the coal industry. When, if ever, the job numbers will approach 2008 levels again, however, is unclear. In the interim, counties that continue to rely inordinately on the coal industry for jobs may be in for a long period of lowered employment by the industry. Policy makers responsible for these regions should consider options for adapting to the energy industry shifts noted in this study. These options may include further support of renewable energy development at the local level, investment in clean coal technologies, and/or instructional aid that helps ex-coal industry employees transition into other types of work.

Table A.1
Example output from EIO-LCA model.

NAICS	Sector	Total economic ($M)	Total value added ($M)	Employee comp VA ($M)	Net tax VA ($M)	Profits VA ($M)	Direct economic ($M)	Direct economic (%)
482000	Rail transportation	0.964	0.467	0.204	0.000	0.282	0.962	99.8
522A00	Nondepository credit intermediation and related activities	0.081	0.050	0.022	0.002	0.026	0.070	86.7
532400	Commercial and industrial machinery and equipment rental and leasing	0.065	0.036	0.016	0.002	0.018	0.062	94.5
48A000	Scenic and sightseeing transportation and support activities for transportation	0.055	0.030	0.018	0.000	0.011	0.052	94.7
230301	Nonresidential maintenance and repair	0.053	0.031	0.026	0.000	0.004	0.048	89.7
523000	Securities, commodity contracts, investments	0.043	0.024	0.019	0.000	0.005	0.031	73.7
324110	Petroleum refineries	0.041	0.003	0.001	0.000	0.002	0.031	74.8

Table A.2
Example job calculations based on EIO-LCA output.

Sector	NAICS	Employee comp added ($M)	Avg. salary[a] ($/job)	Job estimate
–	–	862	32420	26588.5256
Nondepository credit intermediation and related activities	522000	93.1	45119.2	2063.42311
Commercial and industrial machinery and equipment rental and leasing	532400	68.4	43463	1573.752387
Scenic and sightseeing transportation and support activities for transportation	480000	77.9	25215.4	3089.381886
Nonresidential maintenance and repair	230301	110	37200.8	2956.925658
Securities, commodity contracts, investments	523000	78.5	66787	1175.378442
Petroleum refineries	324110	4.97	49980	99.43977591

[a] Average salary per BLS National Industry-Specific Occupational Employment and Wage Estimates (Bureau of Economic Analysis, 2014).

Appendix A

The following tables illustrate how we used the EIO-LCA to estimate job changes in those industry sectors supporting electricity generation operations and maintenance (O&M) activities. The EIO-LCA requires an input value of economic activity, which is explained in detail in Section 3 (page 9). In short, it is the producer price for a sector. The model uses this price along with the NAICS code for the sector and the 2002 BEA Benchmark data set for all NAIC coded sectors to generate an economic output table for the sector and all other industry sub-sectors that support it.

Table A.1 is a portion of such an output table. The actual output is more extensive than this, but in limiting our analysis to O&M activities and their supporting subsectors, we only used the NAICS code, sector title, total economic value, direct economic value and employee compensation (Table A.1).

Of these outputs, we used employee compensation to estimate jobs.

We divided the compensation values by BLS estimates of average salaries for each NAICS code as reported in Section 3 (page 10) of the study to arrive at the job estimates for each NAICS code/subsector. Example calculations are given in Table A.2.

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