Assessment of the Value, Impact, and Validity of the Jobs and Economic Development Impacts (JEDI) Suite of Models

L. Billman and D. Keyser
National Renewable Energy Laboratory

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Technical Report
NREL/TP-6A20-56390
August 2013

Contract No. DE-AC36-08GO28308

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Prepared under Task No. SA12.0335

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Executive Summary

The Jobs and Economic Development Impacts (JEDI) models, developed by the National Renewable Energy Laboratory (NREL) for the U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE), use input-output methodology to estimate gross[1] jobs and economic impacts of building and operating selected types of renewable electricity generation and fuel plants. Input-output analysis is a technique for preparing a rough estimate of economic activity, including gross jobs. Other analytical models and approaches are also used for rough estimates of gross impacts, and for more detailed estimates of net impacts, depending on the needs of the analyst.

As of July 2013, 13 JEDI models for varying energy technologies were available to the public,[2] and three additional models were in development.[3] JEDI models can be accessed at http://www.nrel.gov/analysis/jedi. The website provides assistance in interpretation of results, a summary of inherent limitations of the input-output methodology, JEDI citations, and other valuable information for appropriate application of the models.

This analysis provides the DOE with an assessment of the value, impact, and validity of the JEDI suite of models. While the models produce estimates of jobs, earnings, and economic output, this analysis focuses only on jobs estimates. This validation report includes three topics:

- An introduction to JEDI models, including the input-output modeling methodology, the data used by JEDI, the process for developing JEDI models, and the current status of the suite of JEDI models
- An analysis of the value and impact of the JEDI models, through independent expert reviewer comments, citation and use in published studies, number of users, and international interest
- An analysis of the validity of job estimates generated by JEDI model through:
    - Comparison to other modeled estimates
    - Comparison to empirical, observed jobs data as reported or estimated for a commercial project, a state, or a region.

JEDI models are developed using cost information researched from interviews with project developers and other experts, and are reviewed by other industry experts before being released. The technology cost data, and the input-output coefficients relating outputs of one sector to inputs from a different sector, are updated from new industry information periodically for all models.

[1] Gross job estimates do not take into account net effects on jobs, such as displacement of other jobs by the construction of a renewable energy plant, or economic impacts of potentially changing electricity or fuel prices, etc.
[2] Available: Coal, Geothermal (hydrothermal and enhanced geothermal systems), Marine Hydrokinetic (wave, tidal, ocean current, river hydrokinetic), Natural Gas Combined Cycle, Land-based and Offshore Wind (utility scale), Solar Concentrating Solar Power (trough), Project and Scenario Solar Photovoltaics (four system capacities), Biofuels (cellulosic ethanol), Biofuels (corn ethanol), Biopower, and Petroleum.
[3] In development: Conventional Hydropower, Land-based Wind (community scale), and Transmission.

Value and impact of JEDI models were assessed through the solicitation of expert reviews, the study of citations, the analysis of the numbers of users and model downloads, and the documentation of interest in the tool from other countries. Three economic modeling experts reviewed the JEDI models and their methodology. These reviewers commented positively on various aspects of the JEDI model and provided helpful recommendations for improvements.

JEDI has been used and cited in more than 70 public studies from 2004 to August 2012, including 12 studies in five different peer-reviewed journals. Currently, about 1,700 individuals (as measured by unique emails used during registration) download one or more JEDI models each year. Unique downloads (one model by one user one time during one year) for fiscal years 2010 through 2012 range from 2,700 to 3,300 per year. Lastly, although designed solely for use in the United States, NREL has received inquiries about JEDI from seven foreign countries in the last two years, and studies have been published regarding six additional countries where JEDI has been modified for foreign use.

The validity of JEDI estimates was assessed through comparison to both published modeled estimates and data on empirical observations of jobs associated with renewable energy projects. For comparison to published modeled estimates, three technologies were examined. Comparison of modeled vs. JEDI job results for a solar photovoltaics (PV) study indicated that JEDI results were within 10%–12% lower than the modeled study for direct[4] jobs for the sum of construction and operation and maintenance (O&M) phases. Comparison of an econometric county-level analysis of wind jobs with JEDI results showed that JEDI results were similar: the JEDI results [0.7 full-time equivalents (FTEs)/megawatt (MW) for construction and 0.3 FTEs/MW for O&M] bracket the econometric calculation (0.5 FTEs/MW reflecting both construction and O&M phases) by +/- 40%. Compared to modeled job results for O&M of several corn ethanol plants, JEDI results ranged from 20% lower to 28% higher.

Comparing results between modeled and empirical employment data continues to be problematic due to the many differences between how actual employment data are collected and reported in the United States collectively or by individual companies, and the type of data required by JEDI and other jobs-estimating models. For example, using actual employment data, this analysis found an annual average of 0.7 ongoing jobs/MW at eight wind farms. JEDI estimated an average of 0.05 O&M FTEs/MW for wind farms with the same nameplate capacity and location, which is lower than observed employment. This difference may be due to employment counts often including part-time employees. Comparison of JEDI estimates with solar installation jobs survey data showed that results from JEDI were lower than the surveyed results for residential systems (8 FTEs/MW for new and 11 FTEs/MW for retrofit for JEDI, compared to 33 jobs/MW for all residential installations surveyed). For larger PV systems, JEDI results were very close and slightly higher than the installer survey (15 FTEs/MW to 23 FTEs/MW for JEDI, compared to 12 jobs/MW to 21 jobs/MW for the installer survey).

[4] Direct impacts refer to changes in jobs, economic activity, and earnings associated with the on-site or immediate impacts created by the project scenario. Indirect impacts refer to changes in jobs, economic activity, and earnings associated with upstream linked sectors in the economy, such as suppliers of hardware or equipment. Induced impacts refer to further changes in economic activity and earnings created by changes in household, business, or government spending patterns. These impacts occur when the earnings generated from the direct and indirect impacts are re-spent in the local economy. An example would be increased spending at local restaurants or grocery stores as a result of direct and indirect impacts.

Comparison of JEDI U.S.-based results for wind plants to a recent global study of the wind industry indicated that JEDI results on an FTE/MW basis were lower for construction and higher for O&M. Comparison of JEDI U.S.-based results for installation of solar PV to a recent global study of the solar installation industry indicated that JEDI results on an FTE/MW basis were close to, but lower than, the industry-wide study. Results for distributed PV installations ranged from 7 FTEs/MW to 11 FTEs/MW for JEDI's U.S. results depending on system size, compared to 11 FTEs/MW (no system size specified) for the global study. JEDI results for utility-scale PV installations were almost twice as high as the global study, but the JEDI methodology counted labor hours for engineering, marketing and sales activities while the global study did not. Comparison of several empirical estimates for O&M jobs at corn ethanol plants showed that JEDI results ranged from 9% higher to 21% lower than the empirical estimates.

Based on the assessment of expert review, citations, user download data, and inquiries from foreign countries, the JEDI suite of models appears to be a credible and well-used estimation or screening tool for gross job estimates for the construction and operation of renewable energy power and fuel plants in the United States. Further, based on the above comparisons, subject to the limitations and challenges inherent to any comparisons of jobs estimates, JEDI results are reasonably comparable to these other modeled results and empirical observations.

Expert reviewers and users have pointed out areas for improvement in the models. Several improvement ideas are offered in the concluding section of the report to address further documenting the models' methodology and assumptions, validating default values incorporated in the models, continuing to compare estimates generated by the models to estimates from other models or empirical observations, and improving the user experience.

List of Abbreviations and Acronyms

BEAR	Berkeley Energy and Resource
BNEF	Bloomberg New Energy Finance
CGE	computable general equilibrium
CSP	concentrating solar power
DOE	U.S. Department of Energy
EERE	Energy Efficiency and Renewable Energy
EPA	Environmental Protection Agency
FTE	full-time equivalent
FY	fiscal year
IMPLAN	impact for planning
I/O	input-output
JEDI	Jobs and Economic Development Impacts
kW	kilowatts
MGY	millions of gallons per year
MIG	Minnesota IMPLAN Group
MW	megawatts
NEMS	National Energy Modeling System
NYSERDA	New York State Energy Research and Development Authority
O&M	operation and maintenance
PV	photovoltaics
REMI PI	Regional Economic Models Inc. Policy Insight
RIMS II	Regional Input-Output Modeling System
TCU	Texas Christian University
UI	unemployment insurance
US GAO	United States Government Accountability Office
USDA	United States Department of Agriculture
USDA ERS	United States Department of Agriculture Economic Research Service

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Background

In 2002, the Wind Program of the U.S. Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy (EERE), funded the development of a new spreadsheet-based model to calculate jobs impacts using input-output (I/O) methodology. I/O models apply historical relationships between demand (i.e., specific expenditures within a given sector) and the resulting economic activity to estimate how new expenditures will affect economic development metrics. These metrics include jobs, earnings (wages and employer paid benefits), and economic output, a general measure of economic activity. I/O models are static–they represent relationships between modeled sectors of the economy at a given time period. They also assume that any change in demand, regardless of magnitude, has the same proportional result. However, the structure and relationships between sectors of the economy tend to change gradually over time. Despite this, I/O modeling is a commonly used methodology for measuring economic development activity (Lantz and Tegen 2011).

I/O models produce gross impact estimates, as opposed to net estimates–they do not take into account far-reaching potential changes, such as impacts of changes in utility rates as a result of development, greenhouse gas emissions, health care costs, and property values.

I/O analysis of jobs, earnings, and economic output is one of several modeling approaches that can be used to estimate economic impacts. Each of these approaches has advantages and disadvantages. Table 1 summarizes some of the better known basic and sophisticated approaches, including Jobs and Economic Development Impacts (JEDI).

Table 1. Selected Methods for Jobs and Economic Impact Analysis

	Basic Methods	Moderate Methods	Complex Methods
Approach	Rule of thumb Meta-analysis	Input-output or based on input-output	Computable General Equilibrium (CGE) Econometric System Dynamics—Linear and Non-Linear Programming
Examples	Rule-of-thumb estimates (i.e., "5 jobs/MW") Screening models	Impact Analysis for Planning (IMPLAN)[5] Regional Input-Output Modeling System (RIMS II)[6] Jobs and Economic Development Impacts (JEDI)	National Energy Modeling System (NEMS)[7] Berkeley Energy And Resource (BEAR) model[8] U.S. Regional Energy Policy (USREP) Model[9] Regional Economic Models Inc. Policy Insight (REMI PI)[10] RAND econometric model[11]
Benefits	Easy to use Minimal time requirement Transparent Inexpensive	Easy to moderately easy to use Time requirement can be minimal but varies Can be inexpensive Widely used, accepted	More comprehensive than input-output; can model more scenarios, retrieve more information Able to incorporate changes over time (i.e., dynamic versus static) Flexible
Drawbacks	Results can be limited Often overly simplistic assumptions Inflexible	Not very transparent Many restrictive assumptions (i.e., constant prices) Scenarios limited to changes in demand Difficult or moderately difficult to develop Can be expensive	Not very transparent Assumptions vary Often difficult to operate or modify Most require expensive software or licenses Difficult, expensive to build Data intensive

Table data from EPA 2010 (modified by NREL)

[5] IMPLAN is a commercial model that uses input-output analysis techniques, social accounting matrices, and publicly available data that is widely used for analysis of jobs and economic impacts; IMPLAN is typically used for gross job estimates.
[6] RIMS II is an input-output-based model that uses regional multipliers to help users estimate gross jobs, developed by the Department of Commerce/Bureau of Economic Analysis.
[7] NEMS is a computer-based model that estimates the energy supply and demand to 2035 with regional projections, developed by the DOE Energy Information Administration and used for energy projections; it has been used with input-output methodologies to project jobs and economic impacts.
[8] BEAR is a state-level computable general equilibrium model developed by the Lawrence Berkeley National Laboratory, which can account for many different factors affecting jobs, producing net jobs estimates.
[9] USREP is a computable general equilibrium model developed and maintained by the Massachusetts Institute of Technology (MIT). The model is national, but splits the United States in to multiple regions.
[10] REMI PI is a commercial model that uses hybrid techniques, combining aspects of input-output, econometric, and computable general equilibrium techniques, and produces net jobs estimates.
[11] The RAND econometric model is a commercial tool that uses sets of related equations, and mathematical and statistical techniques to analyze economic conditions over time, generally producing net jobs estimates.

JEDI models rely on two different types of data sets and I/O matrix calculations. First, for industry economic I/O relationships, JEDI models utilize economic data (multipliers and household expenditure patterns) derived from IMPLAN software and state data files purchased from the Minnesota IMPLAN Group (MIG). MIG compiles, and aggregates national and regional economic and demographic data from the U.S. Census Bureau (Department of Commerce), Bureau of Economic Analysis (Department of Commerce), and the Bureau of Labor Statistics (Department of Labor) to calculate inter-industry linkages and the relationships between changes in demand for goods and services, along with the associated economic activity at the local, state, and regional levels.

Second, JEDI provides default costs for each technology, including detail for about one hundred cost categories.[12] The default values represent a reasonable expenditure pattern for constructing and operating the technology in the United States, including the share of expenditures spent locally. However, actual project spending on goods and services can vary significantly by project and location. Therefore, each model has the flexibility for the user to override these default values.

The basic JEDI models are designed to calculate the jobs and economic impacts by state. The expenditure data are adjusted to account for the typical percentage of various project costs that are provided locally (within the state) as opposed to imported from outside the state. Users can adjust these local shares to account for variability among projects and specific locations.[13]

Model Development Process and Status

During the design and development phase of each JEDI model, NREL researchers or affiliates gather and synthesize technology cost data through a literature review, and interviews of project developers, industry representatives, state tax representatives, and others. This discovery approach ensures the use of the most current and accurate technology information available from renewable energy practitioners. Once a draft model is complete, it undergoes internal review by NREL and DOE technology experts and then review by independent experts. External review is typically performed by individuals who have direct project experience and familiarity with project costs and key development and operating parameters. Lastly, JEDI models are reviewed and validated by an expert from the appropriate industry.

JEDI models are publicly available. However, because appropriate application of the models by the user is the prime determinant of the credibility of the resulting estimates, neither NREL nor DOE endorses the results of JEDI analyses performed by others. This caveat is included in the spreadsheet for each model.

The first JEDI model, developed in 2002 and first cited in 2004 (U.S. GAO 2004), assessed the economic impacts of utility-scale land-based wind projects; the initial version was known as the "Wind Impact Model." The models were made publicly available in 2007. Over time, new JEDI models were developed for additional technologies. As of September 2012, JEDI models are

[12] Examples from the wind model include construction materials such as concrete, rebar, construction equipment, roads, and site prep; electrical transformers; electrical cables and wire; and high-voltage line extension; and labor cost categories such as foundation, erection, electrical, management, and miscellaneous. Cost categories reflect what is needed to construct and operate projects and vary among technologies.

[13] Other regional configurations can be analyzed (counties, groups of states) if multipliers for these regions are provided by the user.

available for nine energy technologies (seven in the electricity sector and two in the transportation fuels sector), and seven more are in development (Table 2).

The websites for the JEDI models provide additional information on the models and contact information for additional support. NREL has published numerous reports of JEDI-based analyses, which are always peer reviewed, and have given numerous webinars and other public presentations about JEDI and its results. These interactions with experts and model users offer valuable insights that allow NREL to continuously refine and improve the models after they are published. Table 2 summarizes the status of JEDI model development. JEDI models can be accessed at http://www.nrel.gov/analysis/jedi.

Table 2. JEDI Models Summary and Status (July 2013)

JEDI Module	Energy Sector	Current Version or Status	Year Original Model Developed	Year of Last Update to Default Values: IMPLAN Multipliers (2010 Dataset)	Capital and O&M Cost Data	Cost Input Mix	Local Share
Biopower	Electricity	In development	N/A	2012	N/A	N/A	N/A
Coal	Electricity	C1.11.1—Update planned	2005	2012	2011	2011	2011
Conventional Hydropower	Electricity	In development	N/A	N/A	N/A	N/A	N/A
Geothermal (hydrothermal and enhanced geothermal systems)	Electricity	GT08.02.12	2012	2012	2011	2011	2011
Marine Hydrokinetic (wave, tidal, ocean current, and river hydrokinetic)	Electricity	MHK01.11.01	2011	2012	2011	2011	2011
Natural Gas Combined Cycle	Electricity	NG1.11.01—Update planned	2005	2012	2012	2011	2011
Offshore Wind	Electricity	OSW 02.04.13	2012	2013	2012	2012	2012
Land-based Wind (community scale)	Electricity	In development	N/A	N/A	N/A	N/A	N/A
Land-based Wind (utility scale)	Electricity	W1.10.03—Update planned	2002	2012	2012	2011	2011
Concentrating Solar Power (trough)	Electricity	CSP1.10.02	2006	2012	2010	2010	2010
Solar Photovoltaics (four system capacities)	Electricity	PV1.17.11	2006	2012	2011	2011	2011
Solar Photovoltaics (policy version)	Electricity	PVS4.5.13	2012	2012	2012	2012	2012
Transmission	Electricity	In development; Wyoming-specific done	N/A	2012	2011	N/A	N/A
Biofuels (cellulosic ethanol)	Transportation	C1.10.02	2007	2012	2010	2008	2008
Biofuels (corn ethanol)	Transportation	CE1.10.02—currently being updated	2006	2012	2010	2010	2010
Conventional Fuels (Petroleum)	Transportation	P3.09.13	2013	2013	2013	2013	2013

JEDI Value and Impact

The value and impact of the JEDI models were assessed through feedback from independent expert reviewers, citations, and usage in published studies, numbers of users and downloads, and international interest.

Independent Expert Reviewer Comments

In March 2012, the authors asked three experts on economic impact modeling to provide a technical review of the JEDI models and information available on the JEDI website. The complete reviews are available on request.

The following is a synthesis of observations.

- All the reviewers offered a number of positive comments, including that JEDI is a “valuable resource,” applied a “credible method,” and is an “excellent addendum to the toolbox” of models and calculators available for jobs analysis for renewable energy technologies.
- JEDI suffers from the same limitations and criticisms common to all I/O techniques in general.
- Uncertainties introduced by the use of a variety of assumptions can introduce errors in particular situations.
- Inaccuracies arise from the approximations of the I/O relationships built on the 2002 benchmark tables of the Bureau of Economic Analysis, and aggregating specific costs for these renewable energy technologies into a few industry sectors is difficult.
- The JEDI website provides documentation and caveats on the shortcomings inherent in the methodology.
- Reviewers recommended:
    - The sources for default data should be documented wherever possible.
    - The default data based on actual power plant projects should be updated and more extensively surveyed.
    - Models should be more frequently validated against observed jobs data. Some inconsistencies in terminology should be addressed.
    - All JEDI models should have an accompanying user guide (only two of the nine models have user guides).

Citations in Published Studies

The bibliography at the end of this report includes a selection of published, English-language studies that use or discuss one or more of the JEDI models. An examination of this bibliography indicates:

- Seventy-one different published studies use or discuss JEDI models for the period 2004 to June 2012, as shown in Figure 1. [14] The number of publications increased in 2010 and 2011 to twelve per year. In the first half of 2012, 15 new studies have been published.
- Twelve studies were published in peer-reviewed journals including Energy Policy, Energies, Energy Economics, American Institute of Chemical Engineers Journal, and Renewable and Sustainable Energy Reviews.
- Authors of these studies include representatives of all major stakeholder groups. Examples include:
  - Private sector: General Electric, The Brattle Group
  - Federal agencies and national laboratories: U.S. Environmental Protection Agency, U.S. Department of Agriculture, Lawrence Berkeley National Laboratory, Argonne National Laboratory, and U.S. Air Force
  - Universities: University of California Berkeley, University of Texas, Michigan State University, Utah State University, Arizona State University, Texas Tech University, Rennselaer Polytechnic Institute, Syracuse University, and Northwestern University
  - International institutions: World Bank, University of Spain, National Technical University of Athens, and Fraunhofer Institute.

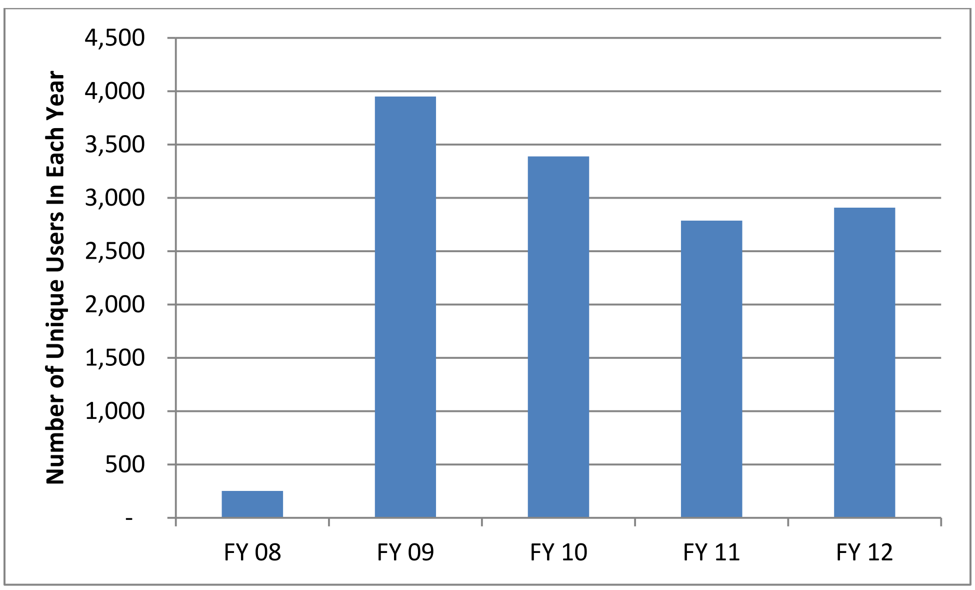


Figure 1. Selected published studies discussing or using a JEDI model

International Interest

JEDI models have been modified and results published for Greece (Tourkolias and Mirasgedis 2011) and North Africa (including Morocco, Algeria, Tunisia, Egypt, and Jordan) (World Bank

[14] The Bibliography section of this paper contains a more complete listing of studies and publications that have used JEDI.

2011). In addition, NREL has received requests for assistance in adapting and using JEDI in Argentina, Turkey, Canada, Puerto Rico, United Arab Emirates, the Netherlands, South Africa, Greece, and Germany (personal communications 2012).

Numbers of Users

In order to download any model, JEDI model users must provide their name and email address. This number of registered downloads serves as a proxy for the number of users. Figure 2 shows that the number of users when JEDI was first publicly launched has declined from 2,400 in fiscal year 2009[15] to about 1,700 in fiscal years 2011 and 2012. The high level of interest in 2009 may have been triggered by the American Recovery and Reinvestment Act of 2008 and its focus on new renewable energy projects.

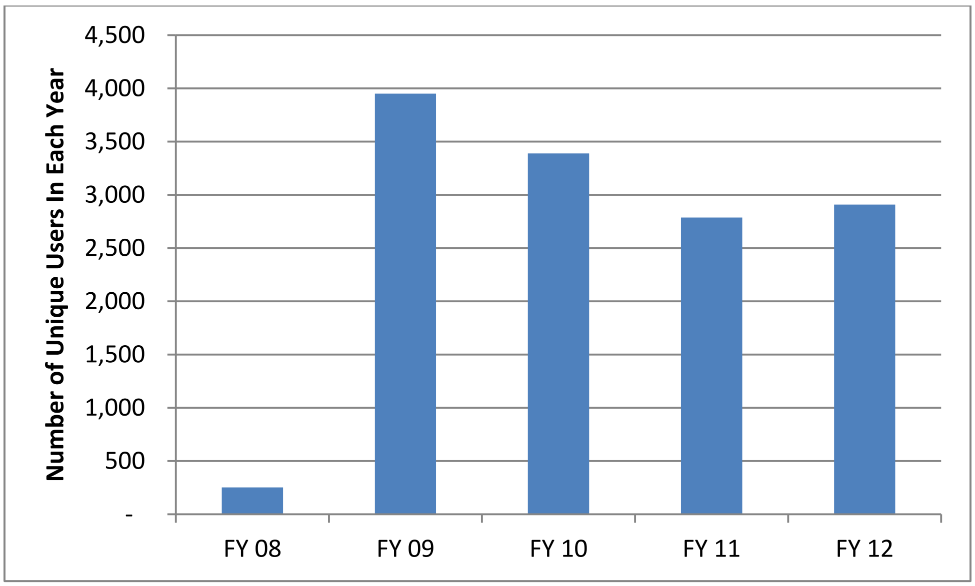


Figure 2. Number of unique JEDI users each year

The JEDI website tracks both the total number of model downloads and the number of unique downloads. Unique downloads are the number of times each model is downloaded, excluding models that are downloaded more than once by the same user. Unique downloads may be understood to represent the level of interest in the JEDI models, but we cannot verify that downloading the model results in someone actually using the model for analysis.

The JEDI website logged 3,389 unique downloads in fiscal year (FY) 2010 (October 2009 through September 2010), 2,787 in FY 2011, and 2,908 in FY 2012. The most downloaded models were wind and solar photovoltaics (PV), followed by concentrated solar power (CSP) trough (Figure 3).

[15] Collection of download data was begun in late fiscal year 2008.

Table 3. JEDI Model Downloads, Oct. 1, 2011 through Sep. 31, 2012

	All Downloads	Unique Downloads
Total	3,916	2,908
Land-based Wind	1,259	909
Solar Photovoltaics	1,008	661
Concentrating Solar Power	444	354
Natural Gas (Combined Cycle)	293	239
Biofuels (Cellulosic Ethanol)	284	237
Marine Hydrokinetic	224	182
Coal	171	126
Biofuels (Corn Ethanol)	166	142

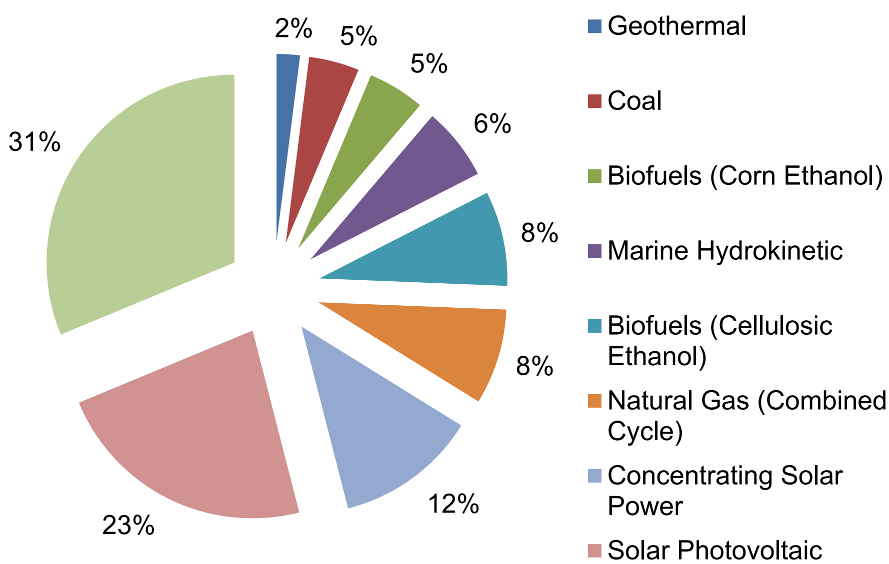


Figure 3. JEDI downloads by model, Oct. 1, 2011 through Sep. 31, 2012

JEDI Validity: Comparisons to Other Jobs Estimates (Modeled)

Studies of modeled jobs estimates have been published by various authors using JEDI, other models or manual calculations based on I/O tables, and other models or manual calculations that do not use I/O tables.[16] Three recent studies provided sufficient detail to allow comparison to an equivalent analysis using one of the JEDI models.

Comparison 1: JEDI vs. REMI PI+ (a Macroeconomic Model) for Proposed Solar Photovoltaics Capacity Additions

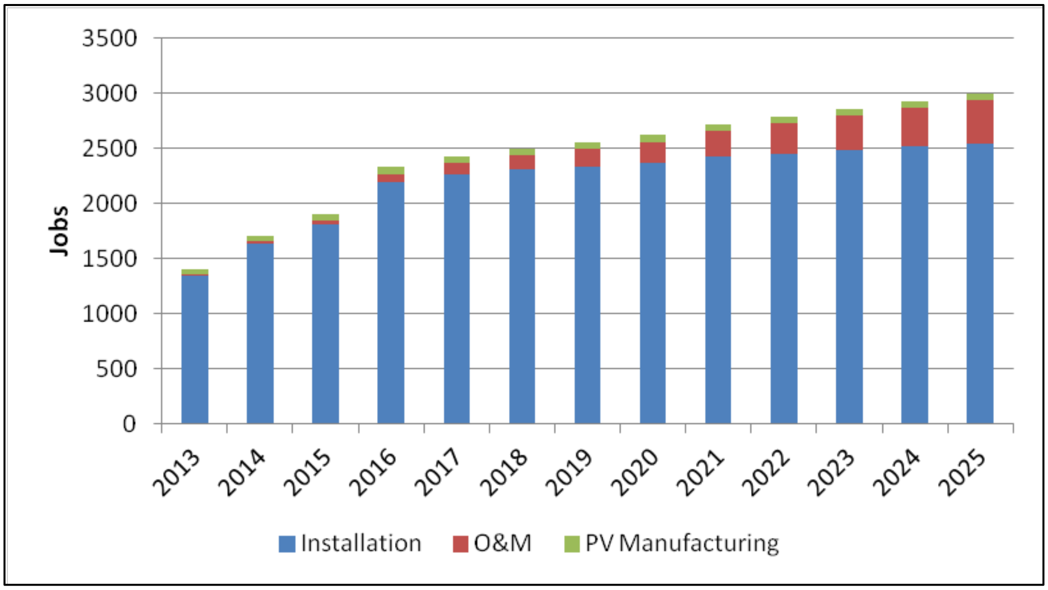
The Power New York Act of 2011 directed the New York State Energy Research and Development Agency (NYSERDA) to evaluate the costs and benefits of increasing the use of solar PV in New York to 5,000 megawatts (MW) by 2025. The impacts of meeting the goals on New York's economy (measured by changes in employment and gross state product) were developed using a Regional Economic Models Inc. Policy Insight (REMI PI+) model. This is an advanced macroeconomic model that combines an I/O model with a dynamic ability to forecast shifts in prices and competitiveness factors over time (NYSERDA 2012).

Methodology

The NYSERDA report contains data that can be used as JEDI inputs for four types of PV systems: residential, small commercial, large commercial, and utility scale. The input parameters included installed project costs, capacity and number of systems installed, financing parameters, percent purchased in-state, percent manufactured in-state, and sales tax assumptions. Two years of the multi-year NYSERDA study were analyzed using JEDI: 2013, the first year of estimated new capacity arising from PV policy incentives, and 2025, the last year of the study, specifically focused on jobs impacts from systems installed in 2025. Figure 4 shows NYSERDA employment estimates from 2013 to 2025.

Job values are listed in the NYSERDA study as "job years," which are defined as one job for the duration of one year. This is assumed equivalent to JEDI's use of full time equivalents (FTEs), meaning one full-time, 40-hour/week job for one person for the duration of one year. The NYSERDA study evaluated a base PV scenario, as well as low-cost and high-cost PV cases; only the base PV scenario was used for this comparison.

[16] All models rely on assumptions, although these assumptions vary between models and techniques. The comparisons made in this report are to illustrate similarities and differences between JEDI and other models and studies, not to portray specific analyses as fact.



Source: NYSERDA 2012, Figure 36 (used by permission)

Figure 4. Phase-specific annual direct job impacts calculated in the base PV scenario case

Results

Table 4 details the results of the JEDI analysis using the inputs from the NYSERDA study. The results for the four system types are shown here as a point of information; the NYSERDA study did not break down results for the individual system types.

Table 4. Detailed Solar PV JEDI Results Using the REMI PI+ Inputs

	Direct, Onsite FTEs
Construction Phase (FTEs)	
Residential	192
Small Commercial	280
Large Commercial	562
Utility	173
Total for 2013	**1,207**
Residential	395
Small Commercial	586
Large Commercial	1,175
Utility	421
Total for 2025	**2,577**
O&M Phase (FTEs per year for 20 years)	
Residential	3
Small Commercial	4
Large Commercial	11
Utility	5
Total for 2013	**24**
Residential	15
Small Commercial	18
Large Commercial	52
Utility	25
Total for 2025	**110**
Sum of Construction Phase and O&M Phase FTEs	
Residential	195
Small Commercial	284
Large Commercial	573
Utility	178
Total for 2013	**1,231**
Residential	410
Small Commercial	604
Large Commercial	1,227
Utility	446
Total for 2025	**2,687**

Source: Inputs from NYSERDA 2012; NREL JEDI results

Table 5 compares the results from the NYSERDA study using REMI PI+ to the JEDI results. JEDI results for direct jobs, summed over construction and O&M phases, were 10%-12% lower than comparable REMI PI+ estimates.

Table 5. Comparison of Jobs Impacts for REMI PI+ and JEDI (Direct Only, Construction plus O&M Phases)

Year	Capacity Built in This Year (MW)	REMI PI+ Direct FTEs	JEDI Direct, Onsite FTEs	Difference (Level)	Difference (Percent)
2013	122	1,400	1,231	-169	-12%
2025	568	3,000	2,687	-313	-10%

Source: NYSERDA 2012, Figure 36 and private correspondence; NREL

Comparison 2: JEDI vs. an Econometric Analysis of Actual Wind Power Plant Additions

Economists at the U.S. Department of Agriculture (USDA), Economic Research Service (ERS) collaborated with researchers at Lawrence Berkeley National Laboratory and the National Renewable Energy Laboratory (NREL) to conduct an *ex post* (after-the-fact) econometric analysis to estimate the county-level (local) economic development impacts of wind power installations. This is the first study to empirically test for the economic development impacts of wind power installations using such a methodology. This study included the set of counties that had installed wind farms in the period 2000–2008 in 12 states in the region that includes the Great Plains and eastern Rocky Mountains (Brown et al. 2012). The analysis examined actual changes in employment and annual personal income in these counties,[17] and the extent that the changes could be attributed to the additional construction and operation of wind farms. In the course of this analysis, the author also examined and compared his results to published project-level case studies of some of these counties. One of these studies was conducted by Texas Christian University (TCU) and NREL using the JEDI Wind model (Slattery et al. 2011).

Methodology

Table 6 compares results for two types of metrics: employment in terms of FTEs/MW of wind capacity installed, and annual personal income in dollars of earnings per MW of wind capacity installed. Table 6 includes results from three sources (Brown et al. 2012):

- Results as calculated in the econometric study
- The range of results from several published project-level studies using I/O models other than JEDI
- Results as calculated by JEDI in Slattery et al., which was also one of the project-level studies in the range of results.

[17] While the econometric analysis was applied to *ex ante*, observed county-level employment data, it is presented in the "Comparison to Modeled Estimates" section of this report. The reason is that it derived an outcome based on a modeling technique and did not employ the empirical "job counting" approach as a basis for comparisons documented later in the report.

The econometric analysis calculated average annual FTEs, normalized per MW of capacity installed, for wind capacity additions over the period 2000–2008. The published studies, cited by Brown et al. 2012, provided results that could also be normalized per MW of capacity and compared to the analysis within this set of counties and this timeframe. The Slattery et al. study examined two specific wind farms in two specific counties in Texas that were constructed in 2008 and are within the timeframe and geographic set of studies by Brown et al.; the total installed capacity is 1,398 MW.

The econometric study distinguished between analyses of the impacts of wind plants that were locally owned from those that were absentee owned. Only the data for the absentee-owned wind farms (the larger data set) are shown in Table 6 because Slattery et al. only analyzed absentee-owned wind farms.

Table 6 shows employment and income impacts econometrically estimated by Brown et al. alongside I/O impacts referenced by Brown et al., and JEDI employment and income impacts estimated by Slattery et al. All three analyses reported similar metrics arising from similar wind projects that are within a similar general time frame.

There are differences between the studies. The time period of analysis varies between studies– Brown et al. focused on 2000 through 2008 while Slattery et al. focused on projects constructed in 2008 and operating between 2009 and 2028. The phase of projects also varies. I/O studies split construction and operating periods, whereas the econometric estimates in Brown et al. combined the two.

Results

Table 6. Comparison of Jobs and Earnings Impacts for an Econometric Study and JEDI

			FTEs/MW				Annual Earnings $/MW (2010$)			
				Other I/O Studies				Other I/O Studies		
Year or Time Period	Project Phase Considered	Capacity Built in this Time Period (MW)	Econometric Results (Brown 2012)	Results Range (Brown 2012)	Number of Studies Consulted (Brown 2012)	JEDI (Slattery 2011)	Econometric Results (Brown 2012)	Results Range (Brown 2012)	Number of Studies Consulted (Brown 2012)	JEDI (Slattery 2011)
2000-2008	Both	15,750	0.50				$11,000			
2000-2008	Construction			0.1-2.6	5			N/A	N/A	
2000-2008 and beyond	O&M			0.1-0.6	7			$5,000-$18,000	6	
2008	Construction	1,398				0.7				$8,000
2009-2028	O&M	1,398				0.3				$13,000

Source: Brown et al. 2012; Slattery 2011

Table 6 indicates that the JEDI construction jobs estimate of 0.7 FTEs/MW was in the lower third of the range of I/O studies (0.1 to 2.6 FTEs/MW). The JEDI O&M jobs estimate was just below the middle of the range of the I/O studies (0.3 FTEs/MW compared to 0.35 FTEs/MW). Compared to the econometric study, the JEDI jobs estimates were similar. The JEDI results (0.7 FTEs/MW for construction and 0.3 FTEs/MW for O&M) bracket the Brown et al. econometric calculation (0.5 FTEs/MW reflecting both construction and O&M phases) by +/- 40%.[18] Similar trends are seen with annual earnings as well.

Brown et al. suggest that, while a strict comparison between the results of the econometric analysis and other jobs studies they examine is not possible, the I/O approach used as the basis of these other studies does not appear to over-state the economic impacts of wind development:

> Interesting, despite a number of known limitations to the standard application of I/O models to estimating economic development impacts, our results are of a similar general magnitude to I/O derived estimated impacts …Though the two results are not strictly comparable, this suggests that I/O models that are used to assess the economic impacts of wind energy (at least at the county or local level) may not be unduly impacted by the generic limitations to those models discussed earlier in this paper and do not appear to be overstating the impacts of wind development. (Brown et al. 2012)

Comparison 3: JEDI vs. Published Sources of Modeled Jobs Estimates for Corn Ethanol Plants

NREL recently prepared a report on the JEDI corn and cellulosic ethanol models (Zhang 2012). Part of that report compared JEDI results for O&M jobs to published results in the recent literature and available databases. This report included a comparison of JEDI results to published results in the recent literature of modeled estimates for corn ethanol plants.

Methodology

The NREL study focused on comparing jobs and/or jobs multipliers for the O&M phase produced by the JEDI model with various published results. A jobs multiplier is defined as the total jobs (direct, indirect, and induced[19]) divided by the direct jobs. The total jobs describes the total effects within the state where the project is located resulting from a single expenditure, so the jobs multiplier describes the expectation that the direct investment will have a ripple effect that will create additional jobs within the state.

Results

Table 7 describes the comparison of published values and JEDI values, where sufficient detailed information was available to calculate comparable JEDI estimates. In this table, "jobs" means

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[18] Econometric estimates are also necessarily net changes, incorporating job losses as well as gains. Because the Brown et al. analysis focuses on county employment, the difference between net and gross changes is somewhat mitigated. Job gains tend to be geographically concentrated (i.e. around the wind site) while losses tend to be difuse (i.e. around the state).

[19] Direct impacts refer to changes in jobs, economic activity, and earnings associated with the on-site or immediate impacts created by the investment. Indirect impacts refer to changes in jobs, economic activity, and earnings associated with upstream linked sectors in the economy, such as suppliers of hardware or equipment. Induced impacts refer to further changes in economic activity and earnings created by changes in household, business, or government spending patterns. These impacts occur when the earnings generated from the direct and indirect impacts are re-spent in the local economy. An example would be increased spending at local restaurants or grocery stores as a result of direct and indirect impacts.

FTEs.[20] Because these are O&M jobs, these jobs would be expected to continue over the estimated 30-year life of a corn ethanol plant.

Table 7. Comparison of JEDI and Published Results (Modeled) for Annual Corn Ethanol Plant O&M Jobs

Study	Description of Published Study	Metric for Approximate Comparison	Published Value	NREL JEDI Value	Difference (% of Published Value)
Swenson (2008)	O&M jobs for a 50 MGY (million gallon per year) dry mill in Iowa in 2005	Direct jobs: Indirect jobs: *Direct + Indirect:*	35 75 *92*	48 50 *98*	37% -33% *6.5%*
	O&M jobs for a 100 MGY dry mill in Iowa in 2005	Direct jobs: Indirect jobs: *Direct + Indirect:*	46 95 *141*	52 85 *137*	13% -11% *-2.8%*
Low and Isserman (2009)	O&M jobs for a 100 MGY plant in Hamilton, IL in 2006	Direct jobs: Indirect jobs: *Direct + Indirect:*	39 97 *136*	52 122 *174*	33% 26% *28%*
	O&M jobs for a 100 MGY plant in Kankakee, IL in 2006	Direct jobs: Indirect jobs: *Direct + Indirect:*	39 152 *191*	52 101 *153*	33% -34% *-20%*
	O&M jobs for a 60 MGY plant in Coles, IL in 2006	Direct jobs: Indirect jobs: *Direct + Indirect:*	35 83 *118*	51 60 *111*	46% -28% *-5.9%*
	O&M jobs for a 55 MGY plant in Harlan, NE in 2006	Direct jobs: Indirect jobs: *Direct + Indirect:*	35 50 *85*	50 51 *101*	43% 2% *19%*

Source: Swenson 2008; Low and Isserman 2009

As can be seen in Table 7, the JEDI results for direct plus indirect compared to several other modeled estimates range from 20% lower to 28% higher than the published results for the sum of direct and indirect jobs. Comparing the sum was considered more valid than the individual direct and indirect estimates due to differences in methodologies of JEDI versus the published modeled results. [21] Further, the sum shows lower variability.[22]

[20] An FTE means one full-time (40 hours per week) job for one person for one year.

[21] These differences could largely be due to how impacts were modeled. For example, within the JEDI framework, contracted service providers are considered to be indirect. Other researchers may assume that these service providers would be directly hired rather than contracted and thus classify them as direct.

[22] Additional statistical analysis was not undertaken due to the small sample size of six cases.

JEDI Validity: Comparison with Observed Direct Employment

A comparison of JEDI model results with observed (also referred to in this report as empirical) job estimates presents several challenges. I/O models relate what is observed about the U.S. economy–that is, economic linkages between sectors at a single point in time – to a discrete, explicitly specified change, such as the construction and operation of a wind farm. I/O models do not factor in outside impacts that occur over time (such as business cycles) or price changes (such as changes in utility electricity rates).[23] Nor are other economic changes considered, such as factory closures/openings, changes in resource use, or changes in productivity.

A scenario modeled in JEDI (such as building a wind farm) may have positive employment impacts. A subsequent analysis of labor data may not show this due to job losses elsewhere in the economy. Job growth due to renewable energy development may cause overall employment to remain unchanged or slow any decline in employment. While this characteristic of I/O models is useful for isolating impacts related to a specific change, it makes comparing JEDI estimates with actual labor data difficult.

Incomplete or uncertain labor data, especially as it relates to clean energy industries, further contributes to the problem of comparing actual job figures with JEDI estimates. Companies or project owners may or may not collect labor data that relate to a particular project. Even if data are available, problems arise with the classification of companies and definitions of employment.

These problems limit any comparisons of JEDI results to real world direct or on-site employment impacts. Detailed studies of actual projects, job sites, and suppliers would be necessary to collect useful employment data throughout the supply chain, so supply chain impacts cannot be counted or compared at this time. When available, direct or on-site employment data can be isolated and associated with an identifiable project along with specific parameters, such as the project's nameplate capacity. Entering capacity and holding all other parameters to their default values allows comparison of JEDI calculations with real-world scenarios.

Comparison 4: JEDI vs. Empirical Land-based Wind Farm Data

Methodology

This analysis incorporates observed jobs associated with the O&M phase of nine operating wind farms that became operational between 2007 and 2010 (Table 8). These facilities were selected because the operator provided NREL with employment information. For each wind farm, nameplate capacity and turbine size were used as JEDI inputs. JEDI default values were used for all other parameters, including technology cost.

[23] Some models that utilize input-output as a part of the analysis are dynamic. In this case, they utilize other processes, such as econometric forecasts to account for changes. These models may or may not produce net (as opposed to gross) estimates.

Table 8. Analysis of Land-based Wind Facilities for Direct, On-Site O&M Jobs

Facility Name	Location	Nameplate Capacity (MW)	Turbine Size (MW)
Hull Wind II	Hull, MA	1.8	1.8
Bluegrass Ridge Wind Farm	Gentry County, MO	56.7	2.1
Peetz Table Wind Energy Center	Peetz, CO	400.5	1.5
Northern Colorado Wind Energy Center	Logan County, CO	174.3	1.5–2.3
Streator Cayuga Ridge South Wind Power Project	Livingston County, IL	300	2.0
Rail Splitter Wind Farm	Logan and Tazewell, IL	100.5	1.5
Ruby Wind Power Project	Pierce County, ND	149.1	2.1
Twin Buttes Wind Farm	Bent County, CO	75	1.5

Source: NREL

Results

Employment at each individual wind facility cannot be disclosed due to confidentiality agreements, but aggregate comparisons of JEDI results with actual information can be presented. Of the wind farms in Table 8, JEDI results in three cases were identical to the number of employees reported by wind farm operators and lower in all the other cases.

Normalized to nameplate capacity, JEDI calculated an average of 0.05 on-site FTEs per MW of capacity installed for O&M. Observed data showed employment closer to 0.07 jobs per MW of capacity installed for O&M. For example, for a 250 MW project, JEDI would, on average, project 12.5 FTEs for O&M while the number of actual jobs (according to this sample) was found to be closer to 17.5. The calculated differences for each wind farm (Table 9) shows that JEDI results ranged from zero difference to seven FTEs less than the observed employment.

Table 9. Differences Between Observed Wind Employment and JEDI FTE Estimates for Direct O&M Phase (Observed Minus JEDI On Site)

Facility Number[24]	Difference Between JEDI FTEs and Observed Employment
1	0
2	-1
3	-2
4	0
5	-4
6	-1
7	0
8	-7

One possible explanation for JEDI results being lower than observed employment is that JEDI estimates jobs as FTEs, whereas companies generally consider the number employed as the total number of employees.[25] For example, two employees who each work 20 hours per week in combination count as one FTE. An employer, however, may consider them to be two employees.

The difference between what organizations consider to be their number of workers and FTEs as reported by JEDI is most significant during the construction period. Many wind farms report the peak number of construction workers. This metric does not make a distinction between full- and part-time workers, nor does it indicate the duration of the construction project and related employment. For this reason this analysis does not compare reported peak construction jobs and JEDI estimates.

Comparison 5: JEDI vs. Empirical Solar Photovoltaic Installation Data

Solar PV facilities differ from wind farms in several ways that affect quantifying the number of employees. A wind farm is typically a large construction project that takes place over a single time period in a concentrated geographic area. Distributed solar PV is installed on residences or commercial buildings and can be distributed across a large geographic area. Rather than a single large construction project, as is the case with a wind farm, solar PV installers can have enough small projects to maintain staffing levels that are consistent over a longer period of time.

It is more straightforward to obtain staffing levels of solar PV installers than for solar PV system maintenance services. Solar PV installers are typically specialized and know both their installed nameplate capacity over the course of a year and the number of staff required to complete these installations. Depending on what element of a PV system is involved, maintenance can be

[24] The "Facility Number" is arbitrarily assigned and observed employment levels are not listed to preserve data anonymity.

[25] The reason for this situation has to do with state unemployment insurance (UI) filings. State UI forms require the employer to submit the number of individuals working for a company each month as well as wages paid. States do not request the number of hours worked by employees or whether an employee works full or part time. These state filings are a significant source of employment information utilized by the Bureau of Labor Statistics, the Bureau of Economic Analysis, and many other organizations that track or estimate employment.

performed by electricians, roofers, or any number of firms and/or occupations that do not specialize in solar PV. For these reasons, this analysis compares JEDI estimates of direct/on-site jobs from construction (referred to as "installation" for solar PV), rather than O&M, to observed employment numbers provided by installation firms.

Methodology

As part of a 2011 study, Friedman, Jordan, and Carrese surveyed thousands of known solar PV installers across the United States, as well as potential installers such as construction companies. Over 1,400 establishments responded, providing information about employment and sales (Friedman 2011). Sales data include what portion of a firm's revenue involves solar PV installations, total installed solar PV capacity, and the average installed capacity. Employment data include full-time employees, part-time employees, and seasonal workers.

Some assumptions about the survey data must be made in order to compare it to the FTEs reported by JEDI. This analysis assumes that part-time employees work an average of 20 hours per week and seasonal workers are employed for four months.

Employment data from the survey also need to be scaled to reflect the portion of an employee's time that was spent installing solar systems. This was accomplished by multiplying reported employment by the percentage of a firm's revenue that came from solar PV installations.

Respondents provided ranges when asked what percentage of their revenue came from solar PV installations. In order to scale employment, a specific percentage needed to be applied. Table 10 shows the ranges and corresponding single values that were used in this analysis. The top range was set at 100%; the survey was sent to many known solar installers, and it is likely that many exclusively install solar systems. Conversely, the survey was sent to many potential installers and it is likely that some do not install solar PV systems at all. For this reason, in order to be conservative, the bottom of the range was assigned zero. The other two ranges, spanning 25% to 75% of firm revenue, were assigned values in the middle of the range.

Table 10. Values Assigned to Survey Ranges for Percent of Revenue from Solar PV Installations

Response	Assigned Value
Most to all of it (76% to 100%)	100%
Half to three-quarters (50% to 75%)	63%
A quarter to almost half of it (25% to 49%)	37%
Less than a quarter (1% to 24%)	0

Source: Friedman 2011

Respondents also provided ranges when asked how much capacity they installed. This analysis assumes values close to range midpoints, as show in Table 11. Installers that indicated installations greater than 2 MW were assigned a value of 5 MW. This value is in line with observed utility-scale solar PV installations that are greater than 2 MW (NREL 2009, unpublished).

Table 11. Values Assigned to Survey Ranges for How Much Solar PV Capacity Was Installed

Response	Assigned Value (kW)
1 to 100 kilowatts	50
101 to 500 kilowatts	300
501 kilowatts to 1 megawatt	750
1.1 megawatts to 2 megawatts	1,500
More than 2 megawatts	5,000

Source: Friedman 2011

Several assumptions must be made to construct JEDI estimates. All JEDI analyses used model default values and California as the project location. Only direct, on-site construction/installation jobs or construction/installation-related services were reported in this JEDI analysis.

Table 12 shows results from the survey and JEDI in terms of FTEs/MW. JEDI estimates differ the most from survey results in the residential category, the largest category in terms of installed capacity. The JEDI model includes two categories of residential: new construction and retrofits (existing construction). The survey did not distinguish between the two, so both JEDI estimates are shown. In this case, JEDI estimates range from 8.1 FTEs/MW to 11.4 FTEs/MW lower than the survey. For all other categories, JEDI estimates are slightly higher than the survey, ranging from 0.9 FTEs/MW higher in medium-to-large commercial systems to 3.1 FTEs/MW higher in utility-scale or large commercial installations.

Table 12. Comparison of Direct, On-Site Solar PV Installation Jobs Reported by Companies vs. JEDI Estimates

		Survey Results			JEDI Results	
Average Installation Type	**Size Range (kW)**	**FTEs**	**Installed Capacity (MW)**	**FTEs/MW**	**FTEs/MW**	**Difference FTEs/MW)**
Residential	<6	5,401	161.9	33.4	22.0 (Retrofit) 25.3 (New Construction)	-11.4 (Retrofit) -8.1 (New)
Small commercial	6-50	456	21.8	20.9	23.2	2.3
Medium to large commercial/ industrial	51-200	283	14.9	19.0	19.9	0.9
Large commercial/ industrial or utility	>201	230	19.5	11.8	14.9	3.1

Source: Friedman, Jordan, and Carrese 2011; NREL (JEDI estimates)

One possible source of variance between JEDI estimates and solar PV installation data is the difference between a company's anticipated workload and actual demand for its services. If a company overestimated demand it may have hired too many workers, resulting in a relatively high number of employees per MW installed. If the company underestimated, it may have asked employees to work additional hours beyond the 40-hour work week. In that case, it would have a relatively low number of employees per MW installed.

Comparison 6: JEDI U.S.-Based vs. Bloomberg Global Wind Industry Study

Bloomberg New Energy Finance (BNEF) (BNEF 2012) developed global average estimates of direct employment in the wind energy sector, including both O&M positions and construction positions. The most comparable estimates from a JEDI wind model are at the national level.

The technology involved in construction and maintenance of wind farms is fairly standard throughout the developed world. Components are bought and sold in an international market. Therefore, this comparison assumes that neither material prices nor labor intensiveness of projects varies significantly across the developed world, and that the Bloomberg global results and JEDI U.S. national results can be reasonably compared. JEDI's direct, on-site jobs results are compared in this analysis solely with the elements of the Bloomberg analysis that are also direct, on-site jobs. Bloomberg jobs data that appear to be related to supply chain or indirect jobs are not included in this comparison. Job impacts are reported as FTEs by both Bloomberg and JEDI.

JEDI wind employment estimates for on-site construction and development are lower than those estimated by Bloomberg's global study, and higher than those for O&M (Table 13). BNEF noted that increasing global productivity is reducing the labor needs of the land-based wind industry. A possible explanation for the lower JEDI results for construction is a productivity difference between the average U.S. and global wind farms.

Table 13. Comparison of Bloomberg Global Wind Study vs. JEDI U.S.-based Direct Impact Estimates for Both Construction Phase and O&M Phase

	Bloomberg FTEs/MW	JEDI (On Site) FTEs/MW
Wind farm construction and development	1.7	0.7
Wind farm operation	0.1	0.5

Source: BNEF 2012; NREL

Comparison 7: JEDI U.S.-Based vs. Bloomberg Global Solar PV Industry Study

Methodology

Bloomberg New Energy Finance (BNEF 2012) also developed global estimates of employment in the solar PV energy sector. The JEDI PV model is for the United States only. Yet as noted in the BNEF wind energy analysis discussion above, PV markets are global and technology is fairly standard across the developed world. Bloomberg estimates can be reasonably compared with JEDI at the national level.

The BNEF study isolated solely the installers (i.e., construction workers), excluding sales and engineering labor, for two categories of PV installations: small scale and utility scale. The JEDI model includes installers, as well as the sales, engineering, and other workers. JEDI also produces results for five PV categories, as opposed to two, as shown in Table 14. JEDI assumes all labor to be available within the United States. All jobs are FTEs, both those reported by Bloomberg and JEDI estimates.

Results

As shown in Table 14, JEDI estimates are close to, though in all cases lower than, Bloomberg's results for smaller installations, ranging from 6.8 FTEs/MW to 10.6 FTEs/MW compared to 11.0 FTEs/MW. For utility-scale installations, JEDI's results are significantly higher—6.8 FTEs/MW compared to 3.5 FTEs/MW. The JEDI estimates include engineering and sales labor, in addition to the installers. Engineering and sales labor could be significantly higher for companies that are selling and designing much larger systems with greater impacts on communities, compared to small companies dealing with single home or building owners, possibly explaining the higher JEDI results for utility scale and lower JEDI results for residential and commercial installations.

Table 14. Comparison of Bloomberg Global Solar PV Study and JEDI U.S.-Based Direct Impact Estimates for Installation Labor

Solar PV Installation Size (Installation/Construction Phase Only)	Bloomberg FTEs/MW	JEDI FTEs/MW
New Residential Installation (3.5 kW, Fixed Mount)	11.0	10.6
Residential Retrofit Installation (5 kW, Fixed Mount)		8.5
Small Commercial Installation (20 kW, Fixed Mount)		9.0
Large Commercial Installation (150 kW, Fixed Mount)		8.3
Utility-Scale Construction (1,000 kW, Single Axis)	3.5	6.8

Source: BNEF 2012; NREL

Comparison 8: JEDI vs. Published Engineering Estimates and Actual Counts of Corn Ethanol Jobs

NREL recently prepared a report on the JEDI corn and cellulosic ethanol models (Zhang 2012). NREL included a comparison of JEDI results for direct jobs for the O&M of corn ethanol plants to published results in the recent literature for empirical estimates for three actual corn ethanol plants and one state-wide industry estimate.

Table 15 indicates that, for four estimates of empirical employee counts, JEDI results for similar corn ethanol plants ranged from 9% higher to 21% lower than the empirical values for direct, O&M jobs.

Table 15. Comparison of JEDI vs. Empirical Measures of Direct, O&M Corn Ethanol Jobs

Study	Description of Study	Type of Study	Metric for Approximate Comparison	Empirical Value	NREL JEDI Value	Difference From Empirical Value (%)
Simonson and Liska (2009)	Wisconsin state-wide corn ethanol industry in 2008 (nine ethanol plants produced 498 million gallons of ethanol and hired 420 full-time and nine part-time employees)	Actual count	Direct employees	425	450 (assuming nine plants at an average production capacity of 55.3 MGY)	6%
John Kneiss (Hart Energy, Personal Communication March 2012)	O&M jobs for a 100 MGY plant in 2012	Discussion with design/ engineering firms and in-place operations	Direct jobs	45-55	52	4%
	O&M jobs for a 50 MGY plant in 2012	Discussion with design/ engineering firms and in-place operations	Direct jobs	41-47	48	9%
Ethanol Across America (2006)	O&M jobs for a 25 MGY plant in Nebraska	Actual count	Direct jobs	33	26	-21%

Summary, Conclusions, and Possible Improvements

Summary

As of August 2012, nine JEDI models for varying technologies are available to the public, and seven additional models are in development. JEDI models can be accessed at http://www.nrel.gov/analysis/jedi. The website provides some assistance in interpretation of results, a summary of inherent limitations of the I/O methodology, current JEDI citations, and other information for appropriate application of the model.

JEDI models have been developed using technology and cost information derived from interviews with project developers and other experts, and are reviewed by additional industry experts before being released. The technology cost data, as well as the I/O coefficients relating outputs of one sector to inputs from a different sector, are periodically updated for all models based on new industry information. [26]

The value and impact of the JEDI models has been demonstrated in these terms:

- JEDI has been used and cited in more than 70 public studies from 2004 to August 2012, including 12 studies in five different peer-reviewed journals.
- Three economic modeling experts have reviewed the JEDI model and its methodology. In general, these reviewers commented positively on various aspects of the JEDI model and provided helpful recommendations for improvements.
- Studies have been published regarding six additional countries where JEDI has been modified for international use.
- The annual number of unique downloads of JEDI models (one model by one user one time during one year) for fiscal years 2010 through 2012 (estimated) range from 2,700 to 3,300. Currently about 1,700 unique users download models each year.

The validity of JEDI estimates was assessed by comparing both published, modeled estimates and empirical observations of jobs associated with specific projects. For published, modeled estimates, the comparisons yielded the following findings:

- Using the same inputs and assumptions, JEDI direct FTE estimates for the sum of construction and O&M phases were 10% to 12% lower than REMI PI+ modeled estimates when modeling an increase in solar PV capacity in New York to 5,000 MW.
- Estimates using statistical (econometric) analyses of empirical county-level economic data for counties that experienced wind development from 2000-2008 were similar to JEDI estimates. The econometric analysis estimated 0.5 FTEs/MW for all jobs, construction and O&M, and JEDI results were 0.7 FTEs/MW for construction-period jobs and 0.3 FTEs/MW for O&M-period jobs.
- Two peer-reviewed journal articles modeled O&M jobs at corn ethanol plants for six scenarios of varying sizes and locations. In the comparison of the sum of direct plus

[26] Additional data can be found in the Department of Energy Transparent Cost Database at http://en.openei.org/wiki/Transparent_Cost_Database.

indirect jobs, the JEDI results ranged from 20% lower to 28% higher than the modeled results.

Comparisons to empirical (observed) jobs is problematic for several reasons, including incomplete collection of jobs data across an entire project, differences in classifications of workers or contractors, and counting of full-time and part-time workers. Detailed, documented studies of actual projects and job sites are rare. For available empirical observations, the comparisons yielded the following findings:

- Analysis of O&M employment data from eight wind farms indicated that JEDI estimated an average of 0.05 FTEs/MW, whereas actual employment estimates averaged almost 0.07 jobs/MW. One explanation for JEDI results being lower is the common practice of companies counting workers rather than labor hours (FTEs).
- Comparison to solar installation jobs survey data indicated that JEDI results were lower than the surveyed results for residential systems (8 FTEs/MW for new and 11 FTEs/MW for retrofit for JEDI, compared to 33 jobs/MW for all residential installations surveyed). For larger PV systems, JEDI results were very close to and slightly higher than those from the installer survey (15 FTEs/MW to 23 FTEs/MW for JEDI, compared to 12 jobs/MW to 21 jobs/MW for the installer survey).
- A comparison for wind employment between JEDI's U.S.-based results and a global study from Bloomberg New Energy Finance indicated that the JEDI U.S. result for on-site construction and development was significantly lower than the Bloomberg estimate (0.7 FTEs/MW compared to 1.7 FTEs/MW). For O&M, the opposite was true—JEDI results were higher (0.5 FTEs/MW compared to 0.1 FTEs/MW).
- A comparison of solar PV employment between JEDI's U.S.-based results and Bloomberg's global study indicated that JEDI's estimates are close to, but lower than, Bloomberg's results for smaller, distributed installations, ranging from 7 FTEs/MW to 11 FTEs/MW for JEDI compared to 11 FTEs/MW. For utility-scale installations, JEDI's results are higher—6.8 FTEs/MW compared to 3.5 FTEs/MW. A possible explanation for the higher JEDI utility-scale estimate is that JEDI includes the soft construction labor (e.g., design engineers and sales labor), whereas Bloomberg includes only actual installers.
- A comparison of data for four estimates of empirical employee counts in corn ethanol plants showed that JEDI O&M results for similar corn ethanol plants ranged from 9% higher to 21% lower than the empirical O&M values.

Conclusion

Based on the assessment of expert review, citations, and user download data, the JEDI suite of models is a credible and well-used estimation and screening tool for gross job estimates for the construction and operation of renewable energy power and fuel plants in the United States. Jobs are an important metric because they are widely analyzed and reported, and are a consideration in decisions made about energy.

Further, based on the above comparisons, subject to the limitations and challenges inherent to any comparisons of jobs estimates, JEDI results were reasonably comparable to these other modeled results and empirical observations.

Comparing and validating job estimates between modeled and empirical employment data continues to be problematic due to the many differences between how actual employment data are collected and reported in the United States collectively or by individual companies, and the type of data required by economic impact models in general. Within the limitations and challenges inherent to any comparisons of jobs estimates, whether between one modeled result and another or between a modeled result and empirical observations, the comparisons documented in this report demonstrate that JEDI results were reasonably comparable to these other sources.

Possible Improvements

Opportunities for improving the JEDI capability were identified during the course of this study from sources such as feedback from model users and JEDI technical assistance. The following ideas are offered as possibilities that could improve both estimates derived from, and interpretation of results for, today's JEDI models:

- Improvements in validation and documentation of default data sources
- Continuing to compare JEDI estimates to modeled and empirical employment data
- Improving consistency in terminology and the interfaces across models
- More consistent availability of model-specific information to help user interpretation and understanding
- Improvements to the employment data collected by various federal and state agencies in terms of adding renewable energy-related economic sectors and targeted questions on employment that would benefit jobs estimating models in general.

Several improvements could help DOE and NREL maximize the value received for the investment already made in this suite of tools, and add value to the ongoing discussions of energy-related jobs in the United States and the global economy. The following ideas are offered as possibilities:

- Expand the suite of models to include additional power generation technologies, such as combined heat and power, fuel cells, nuclear, and other natural gas and coal technologies.
- Expand the suite of models to include fuel technologies not currently in development, such as jet fuel and other advanced biofuels beyond cellulosic ethanol.
- Establish an online JEDI user group to help improve and broaden the appropriate application of the tool, provide a forum for exchange of information, case studies, and ideas.
- Post on the JEDI website periodic summaries of newly published JEDI-based studies, periodic short articles on tips for use or interpretation, and other timely information.

- Transition the tools to web-based applications from the current spreadsheet-based approach, to encourage a wider user base.
- Assist individuals in other countries interested in adapting the JEDI tool for their economies.
- With select industry partners or via carefully constructed industry interviews or surveys, commission more controlled studies to better document actual jobs in all renewable energy technology areas, for direct, on-site jobs.

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