Issues in estimating the employment generated by energy sector activities

June 2011

Sustainable Energy Department

THE WORLD BANK

Content

Acknowledgments 4

Acronyms 5

Executive summary 6

Background 12

Reasons for measuring employment generated by energy sector activities 12

- Project level estimates 13
- Sector and sub-sector level estimates 13
- National estimates 14
- Global estimates 15

Employment generation and dimensions of policy choice 15

Categories of employment creation 17

Methods of calculation of job creation 20

- Survey-based estimates 21
- Model plant data 22
- Input-output based estimates 23

Case studies in measuring employment supported by the energy sector or an energy project 26

- Estimating the employment effects of a specific project 27
- Estimating the effects of a stimulus program 36
- Estimating the total employment supported by an energy sub-sector 40
- Estimating the total employment created by alternative projects 42

Reflections on methods used to estimate employment generated by the energy sector 48

Appendix 1: Comparing two projects: gross, net, and net-net job creation 52

Appendix 2: Derivation from input-output tables of direct, indirect, and induced employment effects, and backward and forward linkages 53

- Direct, indirect, and induced effects 53
- Forward and backward linkages 54
- Using input-output tables to estimate employment supported by a sector: a simplified example 54
- Step 1: The transactions table 55
- Step 2: The matrix of technical coefficients 55
- Step 3: The Leontief inverse 56

Step 4: Calculating direct and indirect employment factors ... 57
Step 5: Calculating induced employment effects ... 58
Step 6: Using the multiplier analysis ... 58
Appendix 3: Summary of recent studies that measure employment creation ... 59
Appendix 4: Calculating average job-years over the life of a plant ... 73
References ... 74

Box 1: Local employment estimated to be generated by a 75 MW solar PV project in the United States . 28
Box 2: Employment generated by a 4 GW wind project and associated transmission (FTE job-years) ... 30
Box 3: Jobs created during construction by the Brookings County-Hampton, Minnesota, 345 kV transmission line ... 31
Box 4: Jobs created in 2013 by the Brookings County-Hampton, Minnesota, 345 kV transmission line, categorized by sector ... 32
Box 5: Employment estimated to be generated in 2020 as part of a deep building energy efficiency retrofitting program in Hungary (000 FTEs) ... 33
Box 6: Direct, indirect, and induced job creation of biofuels programs in South Africa ... 34
Box 7: Job creation by alternative energy sector spending under a stimulus type program in the United States ... 37
Box 8: Jobs created through spending $ 1 billion on alternative sectors of the U.S. economy, in 2007 ... 39
Box 9: Employment effects of a stimulus program in Latin America ... 39
Box 10: Direct, indirect, and induced employment in U.S. oil and natural gas industry in 2007 ... 41
Box 11: Job creation of a solar PV program to install 5GW by 2015, versus an equivalent gas program plus balancing household expenditure in the United States ... 43
Box 12: Direct employment to manufacture, install, construct and operate a solar PV plant ... 45
Box 13: A suggested formula for calculating employment generated by the production of 100 million gallons of biofuels ... 46
Box 14: Comparison of direct job years per GWh for alternative technologies in the United States ... 48

Table 1: Summary of approaches to estimating employment linked to the energy sector or an energy project ... 10
Table 2: Transaction matrix for a closed two-sector economy ... 55
Table 3: Matrix of technical coefficients ... 55
Table 4: The matrix $(I - A)$ ... 56
Table 5: The Leontief inverse $(I - A)^{-1}$ ... 56
Table 6: Direct and indirect effects on output from a unit increase in demand for sector M ... 57
Table 7: Employment related to initial final demands ... 57
Table 8: Employment effect for unit increases in demands for each sector ... 58

Acknowledgments

This paper was prepared by Robert Bacon and Masami Kojima, both of the Sustainable Energy Department of the World Bank. The paper benefited from helpful comments provided by Gonzalo Araya, Milan Brahmbhatt, Chandrasekar Govindarajalu, Javier Morales, Jordan Schwartz, and Michael Toman, all of the World Bank.

Acronyms

B2	a blend of biodiesel-diesel containing 2 percent biodiesel
CGE	computable general equilibrium
CIM	construction, installation, and manufacture
CSP	concentrated solar power
E10	a blend of ethanol-gasoline containing 10 percent ethanol
ELCC	expected load carrying capacity
FTE	full-time equivalent
GDP	gross domestic product
GW	gigawatts
GWh	gigawatt-hours
IMPLAN	impact analysis for planning
IO	input-output
JEDI	job and economic development impact
kV	kilovolts
kW	kilowatts
MW	megawatts
O&M	operation and maintenance
PV	photovoltaic
R&D	Research and development
RE	renewable energy
SPP	Southwest Power Pool

All dollar amounts are U.S. dollars.

Executive summary

Governments often consider the potential impacts of different options on employment in setting policy or examining projects in the energy sector. The employment impacts can be measured in several ways, making simple comparisons between studies on employment misleading. This paper describes the various measures of employment that are widely used and discusses the definitions and methodologies used. Four classes of study, answering different questions about employment creation, are considered:

1. Estimating the incremental employment created by a specific project
2. Evaluating the incremental employment effects of different forms of a stimulus program in which the energy sector is one possible recipient of government spending
3. Evaluating the total employment supported by an energy sub-sector at a moment in time
4. Comparing the employment creation of alternative energy technologies to achieve the same goal, whether it be the amount of power delivered or million dollars of expenditure.

Employment created can be measured as direct (those employed by the project itself), indirect (those employed in supplying the inputs to the project), and induced (those employed to provide goods and services to meet consumption demands of additional directly and indirectly employed workers). A further distinction is made between employment for construction, installation and manufacture (CIM), and employment for operation and maintenance (O&M). When there is interest in the effects on incomes as well as employment, changes in different categories of employment can be multiplied by estimates of wage rates to obtain such information.

An estimation of direct employment for a project requires information on the expenditure on the project, the technology and scale of the project, and the typical employment per dollar spent for that category of project. Such data are taken from surveys of the industry for typical characteristics, the project design specifications, data for representative plants collected by industry or research institutions, or from any combination of these sources. Important factors in ascertaining a project's direct employment impacts are the degree to which manufacturing will be carried out domestically and the duration of the CIM and the O&M jobs.

Indirect employment and induced employment are calculated less often, and require the availability of an input-output (IO) table that can link the output of the project sector to all the supply sectors, both immediate and indirect. Where such a table is available, the multipliers for the sum of direct and indirect employment (type I) or of direct, indirect, and induced (type II) can be calculated. Detailed, up-to-date IO tables are available in high-income countries and in some developing countries. Even where a country does not have domestic data for representative plants or multipliers from an IO table, judicious use of a well designed local survey and the importation of employment multipliers from another country can provide valuable information on the orders of magnitude of employment creation of a project, and enable comparisons to be made between projects and between different government spending packages.

Although IO tables are widely used for estimating employment, multipliers they generate are subject to a number of drawbacks that limits their accuracy. Sectors are not sufficiently disaggregated and some sectors, notably solar and wind power, are typically not identified separately so that coefficients are not fully representative. The models are linear and hence do not allow for effects of scale, are often out of date, and do not allow for substitution caused by changes in prices and wages brought about by large sector investments.

The papers surveyed suggest that the multiplier effects are usually large. The type II multiplier often exceeds two, indicating that the combined level of indirect and induced employment for an energy project is likely to be larger than the direct employment itself. Ignoring such effects is therefore likely to give a misleading impression of the impact of the project on total employment. The cases cited found that the total number of job-years created by the project for O&M could be of a similar magnitude to the number of job years created by CIM, due to the fact that the life of the project was typically many times the duration of the manufacture and construction of the plant or equipment for the project. Renewable and energy efficiency projects tend to have relatively lower O&M and larger CIM components than fossil fuel generation projects. The *timing* of employment impacts also depends on the nature of the projects. For a given amount of CIM expenditure, those having long lead times will likely result in a smaller number of jobs at any point in time than alternatives that have shorter gestation periods.

In calculating the number of job-years that a project might generate, many studies did not provide the results for an appropriate counterfactual. The counterfactual might be an alternative technology to produce the same output (for example, gigawatt-hours per year for a generation project) or a different use of the same total spending. Studies that consider a counterfactual can indicate the number of net jobs that the project would create (or destroy) compared to a specified alternative.

An important counterfactual arises in the case of a government spending program (such as a stimulus package or subsidies). The analysis should evaluate not only alternative spending packages, but also the impacts of the opportunity costs of spending, through cutting spending elsewhere, raising taxes, or borrowing. Studies that have considered the implications of equivalent taxes on employment have found that the net employment created, after taking into account the jobs destroyed through an equivalent increase in taxes to maintain long-run budget neutrality in the face of the subsidies or stimulus expenditure, would be relatively modest for certain categories of spending programs, including a package focusing on renewable energy.

One consequence of energy sector investments for employment has at present received relatively little attention—the impact on the household budget of consumers. Energy efficiency projects, even after households have paid for the costs of the improvement, may save households money, and in this case extra expenditure and employment would result (ECF 2010). Projects that increase the cost of energy to the user (such as mandates for renewable generation that raise average costs) will result in reduced expenditure on all goods and a consequent reduction in employment (Hillebrand et al. 2006; Frodel et al. 2009).

In defining the alternative to a given project, it is possible to compare different projects producing the same output or costing the same amount. Where the cost of achieving a given output is markedly lower for one project than another, these comparisons may provide very different employment numbers. If job creation were the only objective, impressive results could be achieved by using very labor-intensive techniques and, in the extreme, avoiding mechanization altogether, but doing so would be neither efficient nor cost-effective and could harm rather than benefit the economy. That is, employment by itself cannot be used as a basis for project selection.

No study reviewed for this paper compared projects costing the same amount on both employment and output metrics, or compared projects producing the same output on both employment and cost metrics. However, the comparisons between alternative projects based on equivalent output or on equivalent cost did indicate that renewable energy or energy efficiency projects generated more gross employment than fossil fuel projects, even taking into account the employment generated in the extraction, processing, and transportation of the fuel. However, when one or more project alternatives are to be financed through increased public expenditure or subsidies, the employment impacts should be adjusted for negative induced effects of tax policies to maintain budget neutrality. Also, because the studies based on equivalent output or cost lacked evidence on the costs for equal outputs or outputs for equal costs, they did not provide sufficient information to evaluate possible trade-offs that a government might be willing to make.

The level of jobs supported by an energy sub-sector (category 3 above) is a fundamentally different kind of statistic than estimates of changes in jobs resulting from changes in investments or policies in the energy sector. For purposes of evaluating investments or policy impacts, what matters is the *change* in employment and other economic measures, not the *level* of employment. Even if total employment in a sector is high, for example, the change in employment from a particular action could be absolutely as well as proportionately small (or negative).

This review of existing literature suggests that this relatively new area does not tend to provide robust evidence. Data are scarce and there are large uncertainties with published numbers, so that point estimates should be treated with caution. Generally, this literature merits closer scrutiny before taking estimates for employment generation as being reasonably reliable.

In addition to the various unaccounted-for factors mentioned above, another consideration in interpreting the results presented is that the actual impacts on employment—as opposed to estimated potential impacts—will depend not only on the types of projects and policies under consideration, but also on how labor markets may adjust to implementation of these projects or policies. With limited exceptions, calculations of employment generation assume that additional workers with the necessary skill profiles are readily available at prevailing wage rates, including workers to meet indirect as well as induced employment demands. Constraints on worker availability—due to either limits on existing skill sets or the need to bid additional workers away from other sources of employment—typically are not considered. Similarly, potential impacts on the rest of the economy—if capital investments for new energy projects crowd out other types of investment—also are not considered. The empirical significance of these excluded constraints will depend on specific country and energy sector circumstances, but it can be said as a general proposition that estimates of increases in employment caused by new projects or policies are upper bounds on actual increases.

Table 1 summarizes the principal methods used, data requirements, advantages and disadvantages, and examples treated in this paper of approaches to estimating the various categories of employment.

Table 1: Summary of approaches to estimating employment linked to the energy sector or an energy project

Study type	Methodology	Data required	Advantages/disadvantages	Examples of study
Employment created by a specific project	Direct employment obtained from survey or from linking expenditure to employment in an IO table. Duration of CIM and O&M obtained from survey or data for representative plants. Indirect and induced employment multipliers obtained from IO table.	Expenditure on project, size and technology of project, labor employed per unit expenditure on project, import content of manufacture, and local IO table or multipliers taken from a table for another country.	Survey approach allows appropriate specification of technology to be related to direct employment required. Use of multipliers permits full range of employment to be estimated. Accuracy of the method is limited by appropriateness of the IO table and the level of sector disaggregation available, as well as the size of any crowding-out effects not considered.	Pfeifenberger et al. (2010) ECF (2010) Labovitz School of Business and Economics (2010) National Biofuels Task Team (2006)
Employment created by a stimulus program in which the energy sector is one alternative	Allocate total expenditure to sectors of the IO table. Convert direct expenditure on labor into employment from national data on wages per worker. Where information exists, disaggregate labor by category. Calculate indirect and induced employment from IO multipliers. Evaluate employment impacts of an equivalent increase in government taxation via reduction in household disposable incomes. Difference between stimulus program and tax increase provides net employment creation figures.	Information on allocation of alternative stimulus programs to sectors of the IO table. IO table and information on employment per unit expenditure by sector.	Method suitable for broad aggregates of energy sector spending. Extending calculation to include some form of tax increase to maintain budget neutrality can provide an approximate estimate of net job creation. Does not distinguish CIM from O&M jobs and does not easily generalize to calculate job-years over time. Approach has been used to introduce employment categorized by skill level.	Pollin, Heintz, and Garret-Peltier (2009) Pollin and Garret-Peltier (2009) Schwartz, Andres, and Dragoiu (2009)
Total employment supported by an energy sub-sector	Identify all sectors of IO table that relate to specified industry. Convert direct expenditure on labor into	An IO table with sufficient disaggregation of components of selected sub-sector is required, as well as	Approximate estimates of employment can be obtained if the IO table is disaggregated as far as the chosen sub-sector	PricewaterhouseCoopers (2009)

Study type	Methodology	Data required	Advantages/disadvantages	Examples of study
	employment using expenditure and labor data. Calculate indirect and induced employment from IO multipliers. If possible, identify capital expenditure by sub-sector in the year chosen, and by allocating it to types of investment, enter it also into IO framework.	employment data disaggregated on a similar basis.	level, but to obtain accurate figures much finer disaggregation would be required. Evidence from all studies indicates that omission of indirect and induced employment would lead to serious underestimation of total employment supported by the sub-sector. The requirement to be comprehensive would make this a difficult exercise to carry out in countries without a very well-developed statistical service.	
Comparing the employment impacts of alternative projects that deliver the same output or cost the same amount	Define alternative projects on a common metric (either cost or output). Using identical methodology, calculate direct employment, either by a survey or by entering expenditures into an IO table. Use IO multipliers to generate indirect and induced employment. Compare job-years created on an equivalent basis for projects with different durations. Comparisons should be made on a common cost basis (by output) or a common output basis (by cost).	Project-level detail on size of plant, technology, duration of CIM and O&M job, and import content of manufacturing. Links to direct employment either by survey or detailed IO table.	Comparison of projects provides estimates of net job creation (or destruction) of a particular option relative to an alternative. If alternatives are financed or subsidized by the public sector, adjustments are made to account for reductions in household net income as revenues are increased to maintain budget neutrality. Comparisons of employment impacts alone do not indicate changes in net income from employment effects, or changes in net economic value if there are differences in project costs for the same output.	Grover (2007) REPP (2001) Kammen, Kapadia, and Fripp (2004) Wei, Patadia, and Kammen (2010)

Background

Many recent studies and reports on the performance of the energy sector have focused on the employment generated by investment. Advocacy for one or other form of technology stresses benefits in terms of jobs created. Governments, planning their energy futures, are also interested in the job creation benefits and possible identification of skill shortages that may emerge from a large energy program.

Employment created or supported by the energy sector is frequently an issue whenever government support is being considered or provided. Government support for the energy sector can range from subsidies of various forms (World Bank 2010) to mandates (such as renewable fuels standards), non-mandatory targets, and incentives. In all cases the impact on employment can be a consideration in the adoption of a particular policy.

A wide range of definitions of employment generated by energy sector activities have been proposed and a variety of methods have been used to construct such estimates. The purpose of this issues paper is to provide a guide to using such figures or constructing such estimates, and focuses in particular on illustrating different approaches and methodologies used in the last decade in estimating employment created.[1] The study does not aim to provide definitive estimates of the employment generation potential of different technologies.

The paper begins with a brief review of the various reasons why studies have focused on the employment generated by energy sector activities. It then reviews the different categories of employment that are commonly measured and discusses the bottom-up and top-down methodologies widely used for estimating these employment levels. The second half of the paper reviews in some detail certain studies that provide useful insights into methodology, and illustrates some of their typical findings. This section is complemented by a brief appendix review of 35 studies that have made measuring employment in the energy sector their central focus.

Reasons for measuring employment generated by energy sector activities

In the last decade there has been considerable interest in estimating the employment generated by the energy sector. This has ranged from studies at (i) the project level, such as a solar photo-voltaic reserve (CH2MHILL 2009) or a building energy retrofit (ECF 2010); (ii) the whole subsector level, such as the oil and gas industry (PricewaterhouseCoopers 2009); (iii) the

[1] Employment creation examined is in the energy sector except when considering the employment impacts of stimulus packages. For the latter, other sectors—such as transport, health, education, and even the military—may be included. In addition, one paper on a fiscal stimulus in the form of increased food assistance is also discussed (Hanson 2010) because it has informative findings on input-output multipliers.

macroeconomic level via the impact on national employment of increased spending on energy (Pollin and Garrett-Peltier 2009); or (iv) the global level of total employment in various sub-sectors, such as different types of renewable energy (UNEP 2008; REN21 2010). The studies have responded to a number of different questions and purposes, and have also used a wide range of methodologies.

Project level estimates

A government that has made a decision to invest in a particular energy project, having taken into account the costs and revenues as well as possible impacts on environmental externalities of the project and of competing technologies or fuels, may wish also to know the likely effects on employment. These effects include not only the number of jobs created directly in the energy sector, but also in industries supplying the energy sector. The higher employment and wages created by the investment will in turn result in further consumer spending, thus leading to additional job creation. The government's interest arises from not only its concern with the employment level in the economy; a breakdown of the types of employment required could also give an insight into possible areas of skills shortages and training requirements.

Another distinction that is important for policy makers is that between jobs created for the construction, installation, and manufacture (CIM) of a new facility or piece of equipment, and the number of jobs for its operation and maintenance (O&M). Separately identifying CIM jobs created is important for two reasons. First, the duration of the CIM for a single piece of equipment is relatively short—the jobs created will not last unless further orders are received. This stands in contrast to jobs to operate and maintain the plant, which will be required for the life of the plant, typically many times longer than the duration of CIM. Second, manufacturing can take place either domestically or abroad, and in the latter case no direct domestic employment benefits are created.

A different use of statistics on employment generated by a proposed energy project arises when the government is deciding whether or not to invest or support a specific project. In this case the alternatives become important to consider, as well as the whole range of performance indicators and not just employment. For example, the government may look to increase the total electricity generation capacity by a certain amount, and will want to compare all the costs and benefits of choosing a renewable source or a fossil fuel source. Although relative costs, both financial and environmental, will be at the forefront of decision making, governments may also be interested in the employment generation effects of the alternatives. These would include direct jobs—in CIM and in O&M in the domestic market—and indirect jobs.

Sector and sub-sector level estimates

Proponents of different energy sub-sectors, or even the whole energy sector, often wish to portray their importance to the national economy or region (Snead and Barta 2007; Erhardt-Martinez and Laitner 2008). A wide range of statistics is used for this purpose but, in virtually all cases, such studies include a figure on the number of jobs supported by the industry. The larger the number of jobs supported, the more important to the national economy the industry is depicted to be. Lobbyists may use such information to request political and financial support.

Estimates of the number of jobs supported by a sub-sector are usually static, describing the current situation. When faced with possible large government spending programs such as a stimulus package, however, the number of new jobs that will be created over a number of years may be estimated.

In estimating the number of jobs created, there is a natural tendency to take the widest definition to support a case resting on the importance of the sub-sector, citing not only direct jobs within the industry, but indirect jobs created by companies that supply the industry and induced jobs created by consumption from these extra workers hired. Jobs for both CIM and O&M are likely to be included. For projects linked to oil, gas, and coal, it is possible to include the number of jobs created in exploring for, producing, processing, and transporting the fuel itself.

National estimates

Government policies to stimulate the economy through large-scale investment in various sectors require careful evaluation of all likely effects. Governments with a given target spending may well view job creation as an important factor in determining which stimulus package to favor. Tracing all the links to employment from the different packages, which may include spending on the energy sector as one alternative, will be of considerable interest.

Not only will there be direct and indirect employment effects as the energy sector invests and grows, but there will be other effects that may amplify or offset such spending effects. Most important will be the effects due to the opportunity costs of the spending. Strand and Toman (2010) reviewed evidence on the short-run versus long-run benefits of stimulus programs that focused on green programs and concluded that often there was a trade-off between the two. Calculating net employment created by policies to support the renewable energy industry in the United Kingdom, Verso Economics (2011) estimated that for every job created in the renewable energy sector, 3.7 jobs were lost elsewhere. Some studies (see, for example, German Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety 2006) make an important distinction between jobs lost within the energy sector as one fuel is substituted for another as a result of the policies, and jobs lost generally because of the extra budgetary costs of the policy. The government must either spend less on something else, or must raise taxes, or must increase borrowing. All of these will tend to reduce aggregate demand and the number of jobs, including those in the energy sector. Further, large changes in the relative demands for different sectors can produce changes in relative prices, and these in turn can lead to further changes in demands and the associated employment.

Global estimates

Concerns about global warming have led to increasing interest in renewable energy. As an adjunct to information on supply capacity, studies have also estimated the number globally employed by the sub-sector, and the number who might be employed under various growth scenarios. Scenarios include a business-as-usual case as well as deeper penetration of renewable energy substituting fossil fuels. The latter case has drawn attention to the net effect of such substitution on employment. The estimation of global employment is a challenging exercise because it has to rely on different sources for estimates that are unlikely to have used common definitions and methodologies. In addition, it is necessary to extrapolate from countries where there is information to countries with no current information.

Employment generation and dimensions of policy choice

The targeting of higher employment levels associated with a particular energy sector or project should never be used as the single objective of public policy. Other objectives, such as minimizing the total cost of achieving a particular output (both physical and environmental), should be paramount. Technologies that are very labor intensive may be able to meet a particular output goal while creating a great deal of extra employment, but the extra cost of the labor may mean that the total cost of the more labor-intensive project is higher than that of a more capital-intensive project that meets all the same physical requirements. If this extra cost has to be borne by the government, this route to job creation needs to be weighed against other possible routes that may be lower in cost. Moreover, the net increase in total labor income (even before adjusting for opportunity costs of public sector financing) may be small if the more labor-intensive technologies also involve lower-skilled workers earning lower wage rates. Generally, government support to a project or sub-sector cannot be justified on an uncosted assessment of job creation. Nor can analysis of the reduced economic and social burdens of unemployment from a particular project be informative without also considering the reduced burdens of other alternatives projects or policies (including broader measures aiming to reduce chronic unemployment). Where it is desired to take into account the cost of a project, its output, and the employment generated, a cost-benefit analysis should be used. The weight attached to employment will reveal the degree of trade-off that the government would be willing to make in order to achieve a given increment in employment.

At a firm level, the private sector is primarily concerned with financial objectives and less likely to be concerned with a project's job creation potential. Firms do not set out to maximize employment or choose projects that are more labor-intensive unless they are more cost effective. Industry-level lobbying to obtain financial benefits for particular technologies, however, often highlights employment creation as an argument in favor of that industry (NEI 2009).

In the case where governments are looking to macro-economic stimulus packages to create temporary or permanent increases in employment, policies costing the same amount may be compared on their effects on employment creation. As explained by Pollin and Garrett-Peltier (2009) in their analysis of four alternative U.S. spending programs (education, military, clean energy and health care), a given total spending can produce varying numbers of jobs for three reasons:

1. Labor-intensity differs between sectors. The allocation of the spending to different sectors will produce different numbers on jobs depending on the labor-intensity of the sectors where the initial spending is targeted. The authors found that spending on education was more labor-intensive than spending on the military.
2. Domestic content affects the number of jobs created. Even if all of the initial spending package were directed to the domestic economy, supply industries or induced spending may be partially drawn from abroad for some items, thus diverting jobs away from the domestic sector. For example, the authors calculated that the U.S. military personnel spent 43 percent of their income on domestic goods and services, while the civilian population spent on average 78 percent of their income on domestic products. The job leakage from spending on the military linked to personnel hiring or salaries would then tend to be larger than a similar package for health or education.
3. Compensation per worker determines the number of jobs a given expenditure outlay can obtain. The average pay-levels of the different sectors where a stimulus package is directed will affect the number of jobs that can be created for a given expenditure.

These examples show that it is important to specify where and how the stimulus is to be spent, and that quantifying the number of jobs created will require a detailed assessment of the circumstances in each sector.

In virtually all cases, apart from estimating the number jobs presently supported by a sub-sector or sector, it is necessary to specify the counterfactual or business-as-usual scenario against which the proposed energy policy can be compared. The difference between the two scenarios gives the net number of jobs created (or destroyed) by adopting the proposed policy instead of the counterfactual. The counterfactual might be a scenario without extra government spending on energy and without the extra financing cost that this would incur. At a detailed project level, the counterfactual might include a range of alternative technologies for achieving a given outcome—such as energy conserved, energy supplied, or the number of people served with modern energy services. Each alternative creates a number of jobs (gross effect) while the differences between alternatives provide a measure of net job creation.

In the case of alternative large-scale spending programs, such as a stimulus package, studies may compare the net difference between alternative stimulus targets involving the same total spending without asking how many jobs might be lost (common to all cases) due to the financing costs of the package. Where the total costs are different, it would be possible to make a net job creation calculation for each alternative (relative to opportunity costs of financing), and then to compare these two net figures to give a net-net evaluation. In an extreme case, project A might create more gross jobs than project B (net job creation on a project comparison basis) but both could destroy jobs once the opportunity cost of financing these projects is allowed for. Appendix 1 illustrates various cases.

It is essential that the principles of calculation adopted are the same for both the proposed policy and the counterfactual. Although within a given study this is usually the case, it may not be the case across different studies, or the studies may not give sufficient detail to compare the results on an equivalent basis.

An overarching concern for policies to create employment in the energy sector through public spending is the extent to which there will be crowding out, resulting in employment falling elsewhere in the economy. In arguing that public spending in the energy sector can increase employment, it is important to make allowance for partial crowding out. Where there is high unemployment, it is likely that there will not be complete crowding out and that there will be a net increase in jobs. But where the costs of financing the increased spending raise interest rates, private sector investment may fall, potentially reducing employment. Attempts to hire more workers when there is little unemployment are likely to drive up wages rather than create many more jobs until the excess demand for labor is reduced. These considerations suggest ignoring these feedbacks is likely to produce upper bounds on estimates of employment creation. A further consideration is that where government policies support certain energy projects by allowing them to raise prices, consumers will tend to reduce demand for a whole range of goods, thus reducing employment outside of the energy sector.

Categories of employment creation

Whatever the purpose of collecting or estimating the employment linked to an energy project or sub-sector, there are a number of important categories of employment that can be considered. Ensuring that transparent, clear, and consistent definitions are followed is essential for comparing projects or sub-sectors.

The time dimension of a job has to be fully articulated before aggregating employment created from different parts of a project or policy. A job is usually defined in terms of the number of job-years attached to the employment. This depends on how much time each year a job is paid for, and for how many years the job exists. Part-time jobs are converted to full-time equivalents (FTEs) and then scaled by the number of years for which that particular job is required—construction for a few years, maintenance for several years. Some studies calculate the total number of job-years created over the lifetime of the project (Pfeifenberger et al. 2010). Others, in order to compare different projects with different lifetimes, divide the total number of job-years created by the lifetime of the project to arrive at an annual equivalent (Wei, Patadia, and Kammen 2010). Such annual averaging can favor projects with shorter life. For example, a 25-year project creating 30 job-years of employment has a higher annual rate of job-year creation than a project lasting 40 years and creating 40 job-years of employment. To create the extra 10 job-years of the second project some replacement investment would be required, thus increasing the cost of achieving a given employment effect. The time dimension is important for energy-related fiscal stimulus policies where the foremost need may be to create jobs quickly, in the hope that the recovery in the economy will compensate when the initial effects of the stimulus wear off.

Whatever the treatment of time averaging of employment, there are a number of different components of employment that can be aggregated together if required, provided that each component is subject to the same time-averaging procedure.

- Direct effect: the extra employment created or destroyed within a given sector as it responds to an increase in the final demand for its product. The employment created to manufacture a wind-turbine and operate it is one example. Wind turbine manufacture will be of shorter duration than operation.
- Indirect effect: the total extra employment created or destroyed as other sectors expand their outputs in order to supply the inputs required for the output of the given sector, the employment created by yet other sectors as they respond to the demand for their outputs from the sectors supplying the given sector, and so on. The manufacture of steel to supply turbine components creates indirect employment, as does the extra energy required to produce the steel. Indirect effects are typically largely linked to the manufacturing stage of the original demand increase and are therefore of shorter duration. The ratio of the sum of indirect and direct jobs to direct jobs is termed the type I multiplier. Total indirect employment depends on the output purchased from each sector and the employment per unit of output in each of the sectors, so that spending programs that have different direct effects will have different indirect effects also.
- Induced effect: the employment created or destroyed to meet the extra demands from all sectors arising from spending from the higher household incomes created by direct and indirect effects, following the initial increase in final demand for the given sector. The extra workers in the turbine industry, the steel industry, and the power sector spend part of their incomes on a whole range of goods, thus creating extra employment in these sectors, and yet further spending will result from these incomes. Some of the wages and induced employment will disappear once the manufacturing stage is finished, but spending from O&M jobs will have the same duration as the life of the plant. The fraction of extra income spent on goods and services is the crucial parameter and depends on tax rates and savings rates. The ratio of the sum of direct, indirect, and induced jobs to direct jobs is termed the type II multiplier. The magnitude of the induced effect depends on the direct and indirect wage bill generated in each sector by a project; sectors with large wage bills will tend to generate more spending and hence more induced employment.
- Gross effect: the employment created or destroyed in response to a given increase in final demand for the sector, not taking into accounts the effects of any alternative project or offsetting policies. Gross effects may be measured on the basis of direct jobs only, the sum of direct and indirect jobs, or the sum of direct, indirect, and induced jobs. In their

study of transmission and wind generation investments, Pfeifenberger et al. (2010) calculated the gross number of direct, indirect, and induced jobs created, but did not estimate the reduction in jobs that would ensue from the effects of financing these investments.

- Net effect for project alternatives: the difference in employment created or destroyed in response to a given increase in final demand for the sector as met by a particular technology (e.g. wind generation) and by an alternative technology (e.g. gas fired generation) achieving the same incremental energy output. Both may be measured on the basis of direct jobs only, the sum of direct and indirect jobs, or the sum of direct, indirect, and induced jobs, so that the net effect can be calculated for any of the three combinations. Wei, Patadia, and Kammen (2010) calculated the number of direct and indirect jobs created using alternative generation technologies to achieve a given output, but did not consider the job losses that financing these could bring. Since the costs of the technologies would be different, the numbers of jobs lost would also be different.
- Net effect for opportunity cost: the difference in employment created or destroyed in response to a given increase in final demand for the sector as met by a particular technology (e.g. wind generation), and in response to the incremental costs of financing the project (e.g. by increased taxes, or reduced spending on other projects). Both may be measured on the basis of direct jobs only, the sum of direct and indirect jobs, or the sum of direct, indirect, and induced jobs, so that the net effect can be calculated for any of the three combinations.
- Net-net effect for alternative projects allowing for opportunity costs: the difference in net employment created or destroyed by one alternative to reach a given output relative to the employment impacts of the public financing implications, and the net employment created by an alternative project to meet the same output target, again measured relative to the employment impact of the public financing implication of the alternative project. See appendix 1 for illustrative calculations.
- Construction, installation and manufacturing effect: the employment created by the design, manufacturing, construction, delivery, and installation of the plant required to meet the final demand or policy. This is defined for the number of years required to enable a newly ordered plant to be up and running.
- Operations and maintenance effect: the employment required to operate and maintain an energy investment once the plant or equipment is installed, calculated for the duration of the life of the plant or the equipment.
- Backward linkage: the direct and indirect effects on employment by a given sector for a one unit increase in final demand for its output, relative to the average employment creation of all other sectors each facing a similar one unit increase in final demand for their outputs (Rasmussen 1956).
- Forward linkage: the direct and indirect effects on employment within a given sector in its response to an extra unit of final demand arising from all the sectors of the economy,

relative to the average employment created within each sector generated by their supply response to the same stimulus (Rasmussen 1956).

- Employment per standardized unit of output. In comparing the effects of alternative projects on employment, it is important to make sure that the projects are comparable on some agreed output metric. The most common case is that of alternative technologies for generation. The projects can be compared on employment (average job-years) per unit of output, which would be defined as gigawatt-hours (GWh) of electricity generated per year. Certain studies have reported employment per unit of capacity such as megawatt (MW), but a distinction must be made between the nameplate capacity of the plant (peak MW) and the expected capacity utilization of the plant (average MW). Because of the large variation in capacity factors between alternative technologies, the number of jobs created to produce a given number of GWh per year may vary substantially between technologies, while the cost for the same annual GWh will increase with falling capacity factor of a plant. These calculations are illustrated in Wei, Patadia, and Kammen (2010). However, simply scaling by the inverse of the capacity factor does not present a full picture. What matters, particularly for intermittent forms of supply, is their dispatchability (availability when required). The expected load carrying capacity (ELCC) measures the proportion of time a plant is available when there is demand for its output. For example, in California, Herig (2001) noted that solar photovoltaic (PV) plants were available 64 percent of the time at peak demand. Dispatchability as another dimension to consider suggests that, at a plant level, comparison between technologies needs to take into account their likely performance against the load curve.

The backward and forward linkage calculations, often used in discussions of overall industrial strategy, bear an intimate relation to the calculation of indirect employment effects, as discussed in appendix 2. They provide one way of comparing the importance of a sector for employment creation relative to other sectors of the economy.

Methods of calculation of job creation

Once a proposed project has been identified, the new investment defined by output or by expenditure needs to be linked to the employment that it would generate. Estimates of job creation principally use one of two broad approaches, (i) bottom up or (ii) top down. The first uses a survey or model plant data to establish the employment required to manufacture and operate a plant or a specific piece of equipment. This analytical approach has the advantage of being able to be made situation-specific by targeting the appropriate responders. Its disadvantage is the time and cost of carrying out a representative survey.

The second approach is one based on an input-output (top-down) framework that provides a link based on historical data between inputs and outputs for various sectors in the economy, including a link between output and employment. Given the target output or expenditure planned, the level of associated employment generated can be calculated from this link. The advantage of this method is its relative ease of application where there is an input-output (IO) table available, and its ability to provide estimates of indirect and induced employment by a simple manipulation of the IO table. One disadvantage of this method is that the IO table may not be sufficiently disaggregated to provide an accurate estimate for the particular project under consideration.

Survey-based estimates

Survey-based methods of estimating the employment created by an energy project or sub-sector have been applied in a number of studies (see, for example, REPP 2001 and U.K. DTI 2004). They have several advantages over relying on historical links between output and employment in the IO approach:

1. A new survey can target the exact type of investment being considered, whatever the detail of specificity. In addition, where there are important economies of scale to a technology, the survey method can target a plant of the planned size, rather than relying on an industry average for its employment generation potential. One exception is where the technology under consideration is entirely new to the country, in which case firms with commercial experience in the country do not exist. Countries new to the manufacture and assembly of (say) wind turbines would have to take estimates of job-years required for manufacture and for O&M from the experience of other countries. More generally, for all relatively new technologies, allowance might need to be made for learning-by-doing, in which manufacture or operations in the early years are less resource efficient than in the later years: the duration of CIM might be longer (hence more job-years), and the staff required for O&M greater than would be the case once experience has been gained. Productivity gains over time could be figured into studies that consider a series of investments stretching over a number of years. Historical trends in employment per unit of output can be used to provide estimates of improvements in labor productivity, as in REPP (2001) and ESMAP (2011).
2. A survey can identify the expected duration of the CIM process as well as the operational life of the plant, information not available in an IO table. In fact, an IO-type approach would typically have to use survey data or make some crude estimate of CIM duration to obtain this dimension of job creation. Major construction projects, such as an oil production and pipeline project or a large hydropower project, may have different job creation at different stages of construction. For pipelines, the location of job creation will change during the construction process, so that certain categories of jobs change hands between workers as the location of the project moves across the country.
3. A survey can identify the various skills required, the numbers at each skill level, and associated wages. To identify the types of skill required, either a pre-survey can be undertaken to ask firms what sort of skills they would require in order to define the full questionnaire, or else a coarse classification can be used, such as professional, skilled, and unskilled as in the study by the European Climate Foundation (2010). This information can be valuable for identifying potential skill shortages and the need for job-related training programs. The finer the classification of jobs covered in the survey, the

more relevant this information will be for training policies. This allows for a link between the size of the initial spending and the possible employment of different categories of workers who receive different hourly wages, as demonstrated by Schwartz, Andres, and Dragoiu (2009). However, national employment surveys may also provide indications of wage levels for the different categories of jobs. Pollin and Garrett-Peltier (2009) used employment and wage data available from the U.S. Bureau of Employment Accounts to compare a stimulus effect directed to alternative sectors, allowing for different average wages between as well as within sectors. Average military wages were estimated to be 25 percent higher than average wages in health care, leading to lower job creation in the military for a given total expenditure. The authors broke down the employment created under the various programs into jobs in three income ranges: low, mid-range, and high paying, based on the historical distribution of wages. Using an IO-table approach, the authors were then able to analyze direct, indirect, and induced jobs created in the different wage ranges.

4. The survey method can also be applied to all producers in an energy-subsector, or a group of sub-sectors, to provide a detailed picture of current total levels of direct employment.

Although surveys can provide valuable information on the direct employment created by a project or supported by a sub-sector, they also have limitations that the IO approach does not have for some aspects of estimating employment creation:

1. It would be extremely resource-intensive to obtain survey data to estimate indirect and induced jobs, and for this reason researchers almost never rely on surveys for this purpose. Because there are generally multiple supply sectors to a project and a larger multiple of sectors supplying these sectors, a survey of all indirect suppliers would not be feasible. In fact this would come close to carrying out a census of production, on which IO tables are based. Similarly, identifying the pattern of consumption expenditure generated from the increased incomes resulting from the initial demand increase is a task left to national statistical surveys, and this would form the basis of calculating induced employment.
2. In some countries that have up-to-date IO tables providing a fine disaggregation of the energy sector, the cost of carrying out industrial surveys to establish employment patterns may be prohibitively high relative to using the IO table. Where a high level of accuracy, especially concerning direct employment, is not crucial, the survey approach may be second best.

Model plant data

As an alternative to undertaking a survey to establish project characteristics, industry standards exist in some countries for calculating the cost, output, and employment characteristics of a project of a specific technology and of a given size. This bottom-up approach can be utilized to translate the proposed output for a project into the associated direct employment. REPP (2001) provides an early example of this approach. The Job and Economic Development Impact (JEDI) model, developed for the U.S. National Renewable Energy Laboratory, regularly provides updated technical characteristics and costs for projects in the wind, solar, and biofuels sectors. Users can enter their specific plant assumptions into the spreadsheet provided and calculate direct employment and costs. Further, the model uses multipliers from an IO model (IMPLAN[2]) to calculate the associated indirect and induced employment (Pfeifenberger et al. 2010; ESMAP 2011).

The approach of using standardized data for model plants is likely to be accurate in a country where there is considerable experience with the technology under consideration, and where there are industry bodies, national laboratories, or research groups that collate such data. However, as in the case of the REPP study (2001), such a calculation was also possible using more standard national statistics.

Combined use of model plant data (to estimate direct employment generation) and IO data multipliers (to estimate indirect and induced employment) will work well if the specific project has similar supply requirements to those identified in the corresponding sector in the IO table, but will be less satisfactory where the two do not match. For example, a wind power project will have different supply requirements from a hydropower project, but the IO table may have energy as a whole as its finest disaggregation, and an average expenditure in the energy sector as a whole will have to be used to estimate the indirect and induced employment effects of both technologies.

Input-output based estimates

Top-down methods of calculating the employment linked to a given sector output revolve around IO analysis. This provides a series of links between each sector's output, its demands on other sectors, and its demand for labor. For example, the IO table itself provides the amount spent on each input (steel, transport, labor, etc.) to produce one dollar of output from the energy sector. This allows calculation of direct links to employment as well as indirect links through the employment of all the supply industries and of industries supplying the energy supply industries. Induced effects can be calculated by linking the extra household income generated to the spending of households on each sector and hence to the direct and indirect employment required for this extra production. Appendix 2 gives a brief account of IO analysis and the calculation of these employment effects.

IO tables can be used to calculate employment linked to sector- or project-level output and offers the following advantages over bottom-up approaches:

1. In countries where IO tables exist and are frequently revised (annually as in some countries) the calculation of direct employment effects linked to output is relatively simple. In addition to the IO table, estimation of direct employment requires information

[2] MIG, Inc is the developer of the IMPLAN® (**IM**pact analysis for **PLAN**ning) economic impact modeling system. IMPLAN® is used to create complete, extremely detailed social accounting matrices and multiplier models of local economies within the United States. More information is available at http://implan.com/V4/Index.php.

that links sector wage bills to sector employment to generate the relation between the changes in the value of output of a sector and changes in the number of people employed.

2. Indirect employment is calculated by a simple operation on the basic IO table—the calculation of the Leontief inverse. This one operation brings together all indirect links, however remote from the industry in question. Survey methods cannot hope to emulate this part of the estimation and, given that indirect employment may be similar in magnitude to direct employment, this is an important advantage for the top-down approach.
3. The top-down approach can also generate induced employment effects from linking the additional wage income (both direct and indirect), created in response to the initial output change in the energy sector, to the spending from this income in all sectors, the employment this creates, and the further employment created by sectors that have to supply these initial demands from households. This step requires a link from incomes to spending on all sectors, including allocation of the extra income to taxes and savings because not all income earned is spent on consumption.
4. IO tables also provide information on the amount of demands for a sector that are supplied by imports, as well as indirect inputs and labor. This provides an estimate of the amount of a unit increase in demand that will be imported. The greater this fraction, the less domestic employment will be directly created. There will also be a leakage to foreign employment at both indirect and induced stages. The study by Hanson (2010) discussed the treatment of imports and calculated that, for a given $1 billion stimulus to the U.S. economy in the form of food assistance, failure to allow for imports would overestimate the number of direct jobs created by about 10 percent.
5. Where the goal of the exercise is to establish the total employment supported by the energy sector (or sub-sector if the IO table is sufficiently disaggregated) the use of the IO method to calculate all employment supported is likely to be satisfactory. Problems are more likely to arise when a finer level of disaggregation is required.
6. Where an IO table does not exist, using coefficients from a table in another country may be credible in some cases, as in Schwartz, Andres, and Dragoiu (2009). Where the definitions of the sector and the economic level of development are similar, this approach may provide a reasonable first estimate of employment generated by a new demand.

Finally, combined use of survey data and IO analysis exploits advantages of both methods. Even though a survey may provide a superior estimate of direct employment for a specific project, the IO approach can give an estimate of the ratio of indirect to direct employment for the energy sector. This ratio can be applied to the direct employment estimated by the survey. Combined use of survey data to estimate direct employment and IO analysis to estimate indirect employment (by applying the type I multiplier to direct employment) is superior to using only survey data and ignoring indirect employment. A similar multiplier-type calculation can be used to calculate induced employment using ratios from an IO table applied to direct employment calculated from a survey.

The strength of IO analysis—linking together all sectors of the economy in a simultaneous calculation—is also a source of weaknesses:

1. In the great majority of cases the level of sector disaggregation available is limited by the need to include the whole economy in the calculation. In an extreme case all energy activities, apart from fossil fuel extraction, may be placed in a single sector. When a specific project or sub-sector is being considered, the use of IO coefficients that are averaged over a much wider range of activities is likely to produce inaccuracies. A wind turbine project will require different amounts of labor and other commodities per dollar of output than would a hydropower project for both CIM and O&M. Treating all projects as having the same employment characteristics (the average of the sector), both direct and indirect, would also make it impossible to carry out meaningful comparisons between alternative projects. The extreme case of this aggregation problem is shown in the formula used by Álvarez, Jara, and Julián (2009) where they related the total national cost of subsidies to renewable energy per worker employed to the average capital per worker in the economy. This ratio was taken to indicate that renewable-energy jobs required a greater subsidy than the cost of job creation generally. As pointed out by Lantz and Tegen (2009), national average capital per worker is not generally equal to capital per worker in the renewable energy sector. Moreover, a national aggregate includes direct, indirect, and induced employment, whereas the number of renewable energy jobs entered into the formula included only direct and indirect employment.
2. IO tables are typically not updated every year and the interval between updates is several years or more in developing countries. A table that is five or even ten years out of date may introduce errors that are not small because the IO coefficients have changed over time. Trends in labor productivity can result in overestimating the amount of direct employment likely to be generated by an increase in demand. A study of the Malaysian economy, Bekhet (2011) showed that type II multipliers from four IO tables between 1983 and 2000 covering 39 sectors, including three energy sub-sectors, showed large variation in some sectors. Between 1991 and 2000, the type II employment multiplier increased by 58 percent for oil, gas, and mining, by 65 percent for electricity and gas, and by 56 percent for petroleum and coal products. In contrast, Hanson (2010) provided an example from the agriculture and food sectors in the context of the U.S. food assistance program where the type I multipliers (the ratio of direct and indirect jobs created relative to the size of the stimulus) calculated from IO tables constructed 10 years apart differed by only about two percent.
3. In estimating the employment impacts of possible large changes in sector demand, the resulting increase in the demand for labor in the sector may change wage levels and distribution and labor hiring, possibly producing a shift in IO coefficients. Issues of this nature have been considered in the application of computable general equilibrium (CGE) models to changes in demand in the energy sector (ESMAP 2004; Devarajan et. al. 2009).

4. Most IO models consider the expenditure on labor in each sector and link the expenditure to employment through establishing the average wage per full-time equivalent worker based on the total number of workers in the sector (estimated separately from an employment census). The same wage rate can then be matched against increased labor costs associated with extra demand to generate the incremental employment. This procedure has weaknesses. It depends on having employment data based on the same industrial classification as the IO table and for the same year as the table was constructed. The data may not allow for wage differentiation within a sector, although wage rates and labor productivity can vary across sectors.
5. As already noted, *all* calculations of employment impacts based on project-specific jobs per unit output and IO figures for direct employment and job multipliers ignore crowding-out effects. In particular, it is assumed that any increase in labor *supply* required to meet the higher labor *demand* implied by the analysis is readily available at prevailing wage rates. The calculated employment effects thus are an upper bound for the actual amount of employment increase that might be realized. The magnitude of over-estimation depends on specific circumstances of a country's overall economy, labor force, energy sector, and the project being considered. The lower is the unemployment rate for qualified workers, or the less immobile the needed workers are among sectors or geographical locations, the greater will be the degree of over-estimation. Similarly, if the project crowds out other domestic investments because a country faces limits on its overall access to capital markets, the indirect and induced employment impacts will be over-estimated if lost employment from crowded-out investment is not considered. Equally, IO models do not allow for feedbacks onto energy prices that may occur as a result of a large investment in the sector. Prices may rise to enable firms to recover investment costs, leading households to reduce their demand for energy and for other goods, thus lading to a reduction in employment.

Case studies in measuring employment supported by the energy sector or an energy project

A large number of studies and reports have appeared in recent years that have as their focus the estimation of employment associated with the energy sector. Appendix 3 presents a summary of selected studies, with notes on their focus, counterfactual (if any), methodology, comments on limitations of the study, and replicability. These, together with the list of references, provide a starting point for more detailed work on a particular case to be investigated.

Four main types of study have been identified, in addition to studies that survey or bring together reports from elsewhere:

1. Studies that estimate the incremental employment created by a specific project.

2. Studies that evaluate the incremental employment effects of different forms of a stimulus program, in which the energy sector is one possible recipient of government spending.[3]
3. Studies that evaluate the total employment supported by an energy sub-sector at a moment in time.
4. Studies that compare the employment creation of alternative energy technologies to achieve the same goal, whether it be GWh of power delivered, or million dollars of expenditure.

Examples of projects covering these topics are presented in more detail to highlight the methodology used, problems experienced, and results obtained.

Estimating the employment effects of a specific project

An example of a well defined single project study is that of the Teanaway solar reserve in Kittitas County, Washington State, in the United States (CH2MHILL 2009). The project was to construct 75 MW (peak capacity) of a solar PV plant over three years. The purpose of the study was to estimate the income (including local taxes) and employment that would be generated by the project, excluding the revenues from selling the power. No alternative project was considered.

An important feature of any localized project is the treatment of labor and capital imports. The study made two assumptions in this regard. First, in analyzing development costs, assumptions were made about how much of the capital cost, materials expenditure and construction payroll would be out of the county and how much in the county. Second, the labor force for the construction phase was assumed to be recruited half from within the county and half from temporary migrants from outside the county. The latter were assumed to spend their incomes within the county, but their savings and taxes benefitted other regions.

Using these assumptions, the authors estimated the direct number of job-years created within the county over the construction period and during the operational phase. These provided the data that could be entered into the IMPLAN IO model that supplies national average numbers for technical coefficients and for household expenditure. The study did not specify which sectors in the IMPLAN model received the initial investment spending. It was assumed that 70 percent of labor income would be spent, the rest being paid in taxes or saved. Construction was planned to be seasonal (seven months in each year) and seasonal numbers were converted into annual job-years over the three-year period, while the plant was assumed to last 20 years. The estimated direct, indirect, and induced employment created is shown in Box 1.

These estimates highlight the following features of the employment generated:

- The sum of indirect and induced employment was greater than direct employment.

[3] As mentioned in footnote 1, one exception is the paper by Hanson (2010), which concerns only agriculture and food, but this paper is discussed to illustrate methodological issues because of its detailed treatment of employment multiplier effects.

- Indirect employment was almost all concentrated in CIM. O&M hardly required inputs from other sectors.
- The construction phase of the project generated more than twice as many job-years over the project life than did the O&M activities.

Box 1: Local employment estimated to be generated by a 75 MW solar PV project in Kittitas County in the United States

The CIM phase of the project (three years)	
	Job-years/year
Direct employment	225
Indirect employment	403
Induced employment	160
Total	789
Type I multiplier	2.8
Type II multiplier	3.5
Total CIM job-years over project life	2,367
The O&M phase of the project (20 years)	
	Job-years/year
Direct employment	35
Indirect employment	1
Induced employment	13
Total	49
Type I multiplier	1.0
Type II multiplier	1.4
Total O&M job years over project life	980
Total job-years over project life	**3,347**
Average job-years per year of project life	**167**

Source: CH2MHILL 2009 and authors' calculations.

An example of a much larger but still well defined project is the U.S. Southeast Power Pool's proposal to construct nearly 4 gigawatts (GW) of peak wind capacity over five to ten years, supported by extra investment in 345 kilovolt (kV) transmission lines. The wind plant was expected to operate for 20 years. The objective of the study by Pfeifenberger et al. (2010) was to estimate the employment and output generated in the seven states that run the power pool.

For the wind component of the study, the JEDI wind model was used together with employment multipliers drawn from the IMPLAN model. The JEDI model is set up with default data that allow imports from other states to be identified, thus recognizing leakages from each state. It required project-specific information on location, total size (nameplate capacity in MW), and turbine size (in kilowatts, kW). The study changed equipment costs from the default values provided and assumed that all manufacturing took place outside the region. Ninety percent of the construction costs were allocated to the region, and labor costs also allowed for some imported labor (fuller details are provided in the study of the cost breakdowns for CIM and O&M).

Because JEDI does not provide a model for the transmission component, the IMPLAN model was used. Assuming that all manufacturing took place outside the region, the construction and labor costs were allocated to six sectors in the IO table:

electric power generation, transmission, and distribution
construction of other new nonresidential structures
maintenance and repair construction of nonresidential structures
architectural, engineering, and related services
environmental and other technical consulting services
scientific research and development services.

A secondary calculation allowed for some manufacturing within the region, allocated to four sectors:

aluminum product manufacturing from purchased aluminum
plate work and fabricated structural product manufacturing
switchgear and switchboard apparatus manufacturing
wiring device manufacturing.

The results from the employment estimates are shown in Box 2, split into direct, indirect, and induced employment. Transmission was treated as an entirely CIM project with no long-term O&M jobs created, while the wind component had both CIM and O&M jobs. Although wind investment was planned to be spread over ten years, the model was treated as if all construction took place during the first year of a twenty-year lifetime while the life of the plant was assumed to be 20 years, and the total number of job-years over the project life was calculated. For transmission the multipliers were relatively small, partly because the study assumed that manufacturing would take place outside of the region. Nevertheless, the number of indirect and induced jobs created was almost as large as the direct jobs. For the wind component of the project the multipliers were very large with many indirect jobs being created during the CIM phase. These multipliers come from the IMPLAN model and therefore reflect a general U.S. tendency for wind projects to have important backward linkages. These effects in turn generate substantial induced employment. In the O&M phase of the project, the number of indirect jobs created related to materials for site maintenance and parts (accounting for 61 percent of O&M costs) were two orders of magnitude larger than for the solar PV project shown in Box 1 on the basis of generation capacity: 129 job-years for wind against 1.3 job-years for solar for every 100 MW installed.

Box 2: Employment generated by a 4 GW wind project and associated transmission (FTE job-years)

Transmission component of project	
Direct employment	4,929
Indirect employment	1,480
Induced employment	2,041
Total employment	8,482
Type I multiplier	1.3
Type II multiplier	1.7
Wind component of project	
CIM phase (1 year)	
Direct employment	1,821
Indirect employment	11,116
Induced employment	4,136
Total employment	17,072
Type I multiplier	7.1
Type II multiplier	9.4
O&M phase (20 years)	
Direct employment	3,451
Indirect employment	5,154
Induced employment	4,559
Total employment	13,163
Type I multiplier	2.5
Type II multiplier	3.8
Total employment for wind project	**30,235**
Average employment per year of plant life	**1,512**

Source: Pfeifenberger et al. 2010.

An example of a study focusing entirely on a transmission project is provided by Labovitz School of Business and Economics (2010). Five high-voltage power lines were planned for construction between 2010 and 2015, spanning four U.S. states, with a length of 700 miles and estimated direct cost of $2 billion. The purpose of the study was to estimate the total effect on employment, by sector and by state, generated by each of the construction projects. The effects of manufacturing and of any offsetting effect from the financing of the project were excluded. The study took estimates of direct costs, employment, and durations from the consortium responsible for the project. These formed the basic input into the IMPLAN IO model. This model is region-specific and able to calculate indirect and induced employment on the basis of local rather than national characteristics. Indirect and induced employment was derived not only for the 25 most affected sectors but also for a complete list of sectors at a 3-digit level of classification. Imports of indirect and induced expenditures were accounted for in the model, thus reducing the creation of in-state employment. The study did not distinguish between local and labor relocating from outside the region.

Estimates of employment created by the largest single project are shown in Box 3. Over the six-year lifetime of the construction of the Brookings County-Hampton transmission line, the number of indirect and induced job-years was virtually equal to the number of direct job-years. Being a transmission-line project, there were no O&M jobs, and the study did not investigate the number of jobs that would have been created nationwide through the manufacture of components. The study did not convert jobs reported in IMPLAN to FTE jobs. It also made the important observation that adding together the number of jobs from different years does not produce an estimate of the number of people employed by the project, since many jobs last for more than one year. The peak number of jobs of 4,492 was estimated to occur in 2013, corresponding to a minimum for the number of people that would have a job generated by the project.

Box 3: Number of jobs created annually during construction of a 345 kV transmission line between Brookings County, South Dakota and Hampton, Minnesota

Job type	2010	2011	2012	2013	2014	2015	Total period job-years
Direct	46	171	718	2,258	1,315	43	4,551
Indirect	19	71	297	935	544	18	1,884
Induced	27	99	413	1,299	756	25	2,619
Total	92	341	1,428	4,492	2,615	85	9,052

Source: Labovitz School of Business and Economics 2010.

All direct employment occurs in the sector that receives the original injection of demand, for which this study took IMPLAN’s sector 36, construction of other new non-residential structures. IMPLAN then estimates, by sector, the indirect and induced jobs created through the two multiplier processes. The results for the Brookings County-Hampton line project are shown in Box 4 for the top 25 sectors in the peak employment year of 2013. The other 259 sectors accounted for another 2,234 jobs, indicating the very wide spread of these effects. Indirect employment was more heavily concentrated in a few supplying sectors, indicating the nature of the backward linkages for construction, while the relative shares of induced jobs reflect the typical allocation of household budgets across a wide range of items as well as being influenced by the varying labor intensities of the sectors.

Box 4: Number of jobs created in 2013 in the top 25 sectors during construction of the 345 kV Brookings County-Hampton transmission line

Activity area	Direct	Indirect	Induced	Total
Construction of other new non-residential structures	2,258	0	0	2,258
Architectural, engineering, and related services	0	217	4	221
Food services and drinking places	0	31	136	167
Wholesale trade businesses	0	52	40	91
Real estate establishment	0	24	57	81
Employment services	0	54	24	78
Private hospitals	0	0	62	62
Offices of physicians, dentists, and health practitioners	0	0	61	61
Retail stores – general merchandise	0	14	45	59
Retail stores – food and beverages	0	13	42	55
Nursing and residential care facilities	0	0	50	50
Retail non-stores – direct and electronic sales	0	16	33	48
Civic, social, professional, and similar organizations	0	18	25	43
Retail stores – motor vehicles and parts	0	14	28	42
Transport by truck	0	29	11	39
Monetary authorities and depositary credit intermediation	0	17	21	38
Services to buildings and dwellings	0	22	14	37
Legal services	0	22	14	36
Automotive repair and maintenance, except car washes	0	18	17	35
Securities, commodity contracts, investments	0	9	23	32
Retail stores – miscellaneous	0	8	23	31
Private household operations	0	0	30	30
Individual and family services	0	0	28	28
Retail stores – building materials and garden supply	0	7	21	28
Retail stores – clothing and clothing accessories	0	6	21	27

Source: Labovitz School of Business and Economics 2010.

A different type of project-related study was that on building renovation with and without significant energy efficiency improvement in Hungary (ECF 2010). Different paces of project implementation with efficiency improvement, referred to as deep retrofitting, were compared to a baseline where normal levels of retrofitting continued. Each alternative scenario assumed that the government would provide interest-free loans to households. Four-fifths of financial savings from higher energy efficiency were assumed to pay for the loan principal, and the remaining one fifth was added to income. Of this remaining amount, 90 percent was assumed to be consumed, creating induced employment.

The study used a combination of survey type data to estimate direct costs and employment, and an IO model to estimate the resulting indirect and induced employment. The retrofitting programs were analyzed to provide estimates of the crew composition by level of labor skill (divided into professional, skilled, and unskilled) with the proportions differing according to the depth of the program—deeper retrofitting (more rapid building renovation with energy efficiency improvement) required a higher proportion of professionals. Applying different wage rates to the groups and estimating the person-months required for a square meter of retrofitting yielded a total labor cost as well as direct employment to carry out a given amount of retrofitting. A program spreading over a number of years was considered, with the CIM level reaching a peak and then declining. No O&M jobs were deemed to be needed.

The study also calculated the energy saved according to the degree of retrofitting, and, by applying average employment per unit of energy for the economy, was able to estimate the number of energy-sector jobs that would be lost as a result of the program. The direct costs of the program were entered into the "construction" and the "electricity, gas, steam, and hot water" sectors of the IO table. The results for the different categories of jobs created in 2020 under the business-as-usual and in the deepest retrofitting scenario (referred to as deep retrofitting hereafter) are shown in Box 5.

Box 5: Employment estimated to be generated in 2020 as part of a deep building energy efficiency retrofitting program in Hungary ('000 FTEs)

Category of employment created (000s)	Base case	Deep retrofitting
Direct in construction sector:	8	91
professional	*0*	*27*
skilled	*5*	*43*
unskilled	*2*	*21*
Indirect from construction	2	29
Induced from construction	1	21
Type I multiplier	1.3	1.3
Type II multiplier	1.3	1.5
Direct effects from reduced energy sector	0	–3
Indirect from reduced energy sector	0	–6
Induced from reduced energy sector	0	–5
Induced from energy savings consumption	1	11
Total net employment	11	131

Source: ECF 2010.

In this project, where there is a great deal of construction activity, direct job creation was the dominant category. Indirect and induced contributed one third of the total jobs, resulting in relatively small multipliers. The total loss of jobs from reduced demand for energy was 10 percent of the total job creation in the deep retrofitting program. A notable feature of the program, which was assumed to be self-financing under the assumption of zero interest payments, was that it still left households with a surplus from the energy savings, creating a further 8 percent of the total increase in employment.

The California Long Term Energy Efficiency Strategic Plan has generated a number of studies of its implications. The move to invest more in clean energy and encourage energy efficiency will generate jobs requiring different skills. One important aspect of this job creation is their impact on the local labor force. The Donald Vial Center (2001) carried out a study looking at the type of jobs that would be generated, the levels of skills required, and the nature of the existing labor force. This led to an analysis of the nature of training and workplace education that would be required to support this expansion of the energy sector. A major conclusion of the study was that, until 2020, there should not be shortages of workers for most of the program. Only in a few specialized niches might there be significant bottlenecks.

Employment creation has been an important focus of support for liquid biofuels globally. Many developing countries have considered creating or expanding a biofuels industry, and rural development and job creation are among the drivers. The study by the National Biofuels Task Team (2006) addressed the implications for South Africa of developing a program for E10 (a blend of 10 percent ethanol and 90 percent gasoline) or B2 (a blend of 2 percent biodiesel and 98 percent petroleum diesel) to reach a target of 3.4 percent biofuels in total liquid fuels, as a 50 percent contribution to the total renewable energy target for 2013. The study considered financial, economic, agricultural, and fiscal issues and assumed that such a program, utilizing sugar cane, maize, or soybeans as feedstocks, would be viable provided that, especially at start-up, fiscal incentives would be given in the form of lower taxes than those levied on petroleum fuels.

The study considered employment by estimating the number of direct jobs created and the associated number of indirect and induced jobs. Direct job creation was taken from existing employment/output ratios in the different sectors, while indirect and induced jobs were calculated using multipliers from an IO table. The sectors considered were the agricultural sector, the biofuels industry sector, and the refining sector. In the agricultural sector it was assumed that some supply would come from existing crop diversion and some from planting new land. In the latter case it was assumed that unemployed rural labor would be available to undertake the work. The petroleum oil refining sector was assumed to lose jobs as demand switched from traditional gasoline and diesel to the new biofuels. The biofuels sector itself included both CIM and O&M jobs. The study did not distinguish full-time from part-time jobs, nor did it consider the duration of O&M jobs versus those of manufacturing. However, since the great majority of jobs created were related to agriculture (and its associated indirect and induced employment), the annual total given in the study largely represented a sustained level of employment. The results of three scenarios, E10, B2, and the combination of the two, are given in Box 6. The direct impact in agriculture provided the great majority of jobs, with the loss of jobs in the refinery sector being smaller than the increase in jobs in the equivalent biofuels sectors.

Box 6: Number of jobs (direct, indirect, and induced) created to meet alternative biofuels targets in 2013 in South Africa

	Refining	Biofuels	Agriculture	Total
E10	–4,771	11,025	40,216	46,470
B2	–1,095	732	8,183	7,820
E10 + B2	–4,952	11,859	48,399	55,306

Source: National Biofuels Task Team 2006.

A study by ESMAP (2011) analyzed the potential for a concentrated solar power (CSP) industry in North Africa with the possibility of exports to the European market. The implications of different growth scenarios on manufacturing output and employment were investigated on the basis of representative plants. Employment per plant was taken from local survey material, and indirect employment was obtained from multipliers taken from JEDI. An important area of focus in this study was the investigation of a potential export market for the manufactured components based on obtaining economics of scale in a high growth scenario. Estimates of employment (in FTEs) by year (taking into account CIM and O&M) were obtained for five countries in the Middle East and North Africa.

Some studies have paid explicit attention to the implications for employment of the costs of a project. Verso (2011) calculated the costs of subsidies to the renewable energy program in the United Kingdom and compared the estimated job creation of the program with the number of jobs that could have been created if the same expenditure had been spent on other public infrastructure or if the value-added tax had been cut by an equivalent amount. A tax cut was estimated to generate considerably more jobs than the subsidies to renewable energy, but the extent of the net job loss of the renewable energy program depended strongly on the assumed propensity to spend from the extra income generated by tax cuts.

Roland-Holst (2010) analyzed effects of California’s Global Warming Solutions Act on the state’s economic growth, employment and income. Policies considered included auctions of output-based pollution permits in which a fraction of the revenue received was recycled via income-tax reduction (cap and dividend). The study used the Berkeley Energy and Resource model to simulate the dynamic effects of such policies, and concluded that the recycled incomes could actually generate more jobs than were destroyed by the effects of the higher costs placed on firms by the cap because demand growth was more employment-intensive than in the sectors in which growth would be lowered.

Hillebrand et al. (2006) analyzed the German experience with the government’s support for renewable energy and pointed out that the compulsory compensation scheme introduced to encourage the introduction of renewable energy would result in an increase in the costs of generation and hence in an increase in prices to consumers. Their study estimated the creation of jobs through the increased investment in renewable energy plants to meet a target renewable share by 2010, and the loss of jobs through the reduction in household expenditure brought about by higher energy costs. Because investment was estimated to be front-loaded, the study estimated that there would be positive job creation in the early years of the program, but that by the end of the period there would be a net job loss. The estimates were sensitive to assumptions about trade. It was recognized that a large share of plant equipment would need to be imported early on due to lack of domestic capacity, but it was suggested that the rapid expansion of the domestic market could turn Germany into a net exporter of renewable technology, leading to domestic job creation. Similar points with respect to the impact of higher energy prices were made by Frondel et al. (2009) in their analysis of the actual costs of Germany’s promotion of renewable energy technologies between 2000 and 2009. They concluded that the net employment effect might have been even negative.

Estimating the effects of a stimulus program

Economic stimulus programs are by their nature designed to create employment, and a primary point of concern is to identify areas for spending that are particularly successful in generating employment. Others issues, such as reducing greenhouse gas emissions or reducing dependence on imported oil, have also been investigated in studies analyzing the effects of alternative stimulus packages. Because of the very large fiscal size of many such programs, there is also concern about the net employment effects, allowing for the impacts of how their funding is undertaken (as well as potential for crowding out other investments, which is rarely considered). Three studies are discussed below because their methodologies provide useful insights for other work involving the estimation of employment effects of spending on energy projects.

Pollin, Heintz, and Garret-Peltier (2009) considered a program in which a fixed sum was to be spent on either fossil fuels (oil and gas, or coal) or on a mixture of energy efficiency improvement measures (building retrofits, mass transit/freight rail, or smart grid) and renewable energy (wind, solar, or biomass). Direct, indirect, and induced employment was calculated for each activity from the IMPLAN IO table, making allowance of domestic content in each case. Two important adjustments were made to the method of calculation. First, recognizing that the sectors in the IO table did not contain sufficiently fine detail to match some of the policies exactly, the given injection of spending was spread across a number of sectors to obtain a more realistic picture of the direct impacts. For example, for the solar option 30 percent was allocated to the construction sector and 17.5 percent to each of hardware manufacturing, electrical equipment, electronic components, and scientific and technical services sectors. The direct employment effects were calculated using these assumptions, linking output to total employment in each sector in the IO table based on census data. Indirect and induced job creation could then be derived using the multipliers from IMPLAN. Box 7 compares the job creation potentialities per million dollars of spending on various energy alternatives. The authors recognized that fossil fuel industries would not require large amounts of new plant construction and associated O&M activities, and concluded that energy efficiency and renewable energy would generate far more jobs per dollar spent. The alternative programs were not compared on the basis of energy generated or saved per dollar spent, nor was an estimate made of the jobs that would be lost through the need to fund the stimulus program.

Box 7: Job creation by alternative energy sector spending under a stimulus type program in the United States

Job creation per $ million of spending

Energy source	Direct jobs	Indirect jobs	Induced jobs	Total jobs
Oil & natural gas	0.8	2.9	2.3	5.2
Coal	1.9	3.0	3.9	6.9
Building retrofits	7.0	4.9	11.8	16.7
Mass transit/freight rail	11.0	4.9	17.4	22.3
Smart grid	4.3	4.6	7.9	12.5
Wind	4.6	4.9	8.4	13.3
Solar	5.4	4.4	9.3	13.7
Biomass	7.4	5.0	12.4	17.4

Job creation by sector in percentages

Sector	Extraction	Agriculture	Manufacturing	Construction	Utilities	Trade	Transport	Administration /professional
Oil & gas	14.6	0.4	13.9	2.4	11.3	6.6	13.1	37.5
Coal	41.6	0.3	13.1	0.9	7.8	5.9	6.8	23.6
Building retrofits	0.5	1.4	13.6	61.5	0.1	7.9	2.5	12.4
Mass transit/freight rail	0.3	0.6	7.8	21.7	0.1	4.4	54.4	10.7
Smart grid	0.4	0.6	38.1	15.7	0.2	6.3	2.8	35.9
Wind	0.6	0.9	47.4	20.3	0.2	7.1	3.7	19.8
Solar	0.5	0.9	37.4	23.7	0.2	6.9	3.2	27.4
Biomass	1.3	60.4	20.6	0.4	0.2	3.8	2.8	10.5

Job creation by education level per $ million of spending

Education qualification	Green investments	Fossil fuels
Bachelor's degree or above: average wage of $24.50/hour	3.9	1.5
College but no bachelor's degree: Average wage of $14.60/hour	4.8	1.6
High school or less: Average wage of $12.00/hour	8.0	2.2
Total	16.7	5.3

Source: Pollin, Heintz, and Garrett-Peltier 2009.

The authors also obtained more detail on the nature of the jobs generated. By tracing the indirect links and induced spending by sector, they identified employment generation by sector. Box 7 indicates the percentage breakdown of the employment among the eight sectors examined for each of the spending programs. The heavy concentration of coal jobs in the extraction sector and of biomass jobs in the agricultural sector can be seen from the results.

A further disaggregation concerning the type of jobs created was possible using information from the population survey. This information provided weights for three education levels for each sector. For example, it was possible to identify within the manufacturing sector the proportion of employees that have a high school degree and no college experience, that have college experience but no bachelor's degree, and that have a bachelor's degree or more. These percentages were applied to the sector estimates of total job creation by the various programs. For an average green program (drawn from the energy efficiency and renewable energy options) versus an average fossil fuel option, the jobs created by education level for an additional million dollars of spending are also shown in Box 7. The green program not only generated more jobs, but a larger proportion was low-income jobs, where unemployment may be more concentrated.

A different perspective on the employment creation of a stimulus package was provided by Pollin and Garret-Peltier (2009). This study considered broad categories of spending—military, clean energy, health care, and education—and assumed the same total spending in each case. As an alternative, the option of cutting household income tax by the same amount was also modeled. This was included as an alternative stimulus option, but its reverse, a tax increase of the same amount, can be seen as measuring the employment consequences of financing the stimulus package through tax increases. In practice such tax increases would be delayed until after the economy had recovered, but the relative size of the job creation and job destruction is important when trying to draw lessons from the effects of a stimulus program.

The methodology followed is similar to that of Pollin, Heintz, and Garrett-Peltier (2009). First, direct, indirect, and induced employment was estimated injecting $1 billion into each of the sectors. The authors then divided the resulting jobs into education levels using the historical data in each sector and, using associated annual wage earnings, provided a breakdown of new jobs by wage category. The results are shown in Box 8. Spending on education created the most jobs, and spending on the military created the least jobs. As explained by the authors, three factors were involved in the different direct job creation levels: the average wage, the labor intensity of the sector, and the import propensity. Tax cuts created more jobs than spending on the military, but less than spending on other target sectors. If tax increases destroyed as many jobs as tax cuts created, then the employment effect of such spending programs financed through taxes would have created net jobs for all options except military spending. However, for the renewable energy program, the net number of jobs created would be relatively small. The larger share of lower-income jobs created by tax cuts (48 percent) relative to clean energy (33 percent) is notable.

Box 8: Jobs created through spending $ 1 billion on alternative sectors of the U.S. economy, in 2007

Job creation per $ billion spending

	Direct jobs	Indirect jobs	Induced jobs	Total jobs
Military	7,100	1,800	2,700	11,600
Clean energy	7,500	4,700	4,900	17,100
Health care	10,400	3,600	5,600	19,600
Education	16,900	3,900	8,300	29,100
Tax cuts	6,900	3,700	4,200	14,800

Job creation by annual wage range per $ billion spending

Wage range	Below $32,000	$32,000–$64,000	Above $64,000
Military	4,327	6,194	1,079
Clean energy	5,557	9,871	1,556
Health care	7,889	10,094	1,067
Education	10,650	15,976	2,474
Tax cuts	7,148	6,572	1,080

Source: Pollin and Garrett-Peltier 2009.

Schwartz, Andres, and Dragoiu (2009) developed a method of analyzing the effects of a stimulus program on employment in Latin America by importing certain information from the United States. In the absence of a regional IO table, they based multipliers for indirect and induced employment on values from a U.S. model constructed by the Federal Highway Administration. A stimulus package of $1 billion was simulated for investment in various infrastructure options and, using information on average Latin American labor market wages, estimates of employment were derived. The study was able to estimate the share of direct expenditure going to labor from sector-based studies in the region. Allowance was made for the import of equipment and materials. For a sub-group of projects, the indirect and induced employment effects were calculated, including indirect employment generated abroad. The results are shown in Box 9 . The greater reliance on domestic content for hydropower and highways projects was reflected in the higher employment estimates obtained.

Box 9: Number of jobs created per $1 billion of spending by a stimulus program in Latin America

	Direct	Domestic indirect	Foreign indirect	Induced	Total
Wind	320	456	1,049	599	2,294
Solar	1,220	532	1,240	1,533	4,525
Hydro	4,400	3,990	1,698	10,141	20,229
Highways	6,055	6,864	2,337	13,955	29,211

Source: Schwartz, Andres, and Dragoiu 2009.

For some projects the study was able to disaggregate the job market into skilled workers (hourly wage of $6) and unskilled workers (hourly wage of $3) in breaking down the allocation of total stimulus expenditure. For example, in a rural electrification program in Peru, 14 percent of total expenditure would go to skilled workers, 7 percent to unskilled workers, 26 percent to domestic inputs, and 53 percent to foreign equipment. At the wage rates assumed and 2,000 working hours a year, this would have generated 23,000 direct jobs in the year of stimulus spending, assuming that there was an instant response. To the extent that unskilled workers tend to spend a higher fraction of income than skilled workers, programs that target investments with a higher proportion of unskilled workers will generate more induced employment.

Although there were no suitable local IO tables available for the Latin American region, the use of a hybrid approach linking locally estimated direct impacts (on labor cost and import shares) to multipliers from a U.S.-based model generated results that were certainly more representative than those that would have been obtained by omitting indirect and induced employment. As a further refinement tables constructed for certain developing countries might provide an improved approximation to the multiplier analysis.

Estimating the total employment supported by an energy sub-sector

A study by PricewaterhouseCoopers (2009) provides an example of an approach to estimating a snapshot of the total employment supported by an energy sub-sector for a particular year. This study calculated numbers for each state within the United States, as well as for the whole country, for the oil and gas industry. The study followed a standard approach of estimating direct employment from industry-level information and then using multipliers from an IO table to calculate indirect and induced employment. Three features of the study are relevant to attempts to carry out a similar exercise elsewhere:

- <u>The treatment of capital expenditures at a moment in time.</u> The industry's capital expenditures were taken from an annual survey of capital and translated into investments by type that could then be entered into the detailed IO matrix.
- <u>The treatment of inter-state trade</u>. The IO model used (IMPLAN) generated employment results within a state, making allowance for leakages to imports from other states but not counting these exports as job-creations activities in other states. To ensure that the sum of state-level employment generated by the sector was equal to national employment generated by the sector, the authors allocated the cross-state effects to the 50 states in proportion to each state's share.
- <u>The detailed level of industry disaggregation for the estimation of direct employment.</u> The study is notable for the level of disaggregation utilized. Direct employment was estimated for the following industries:

  oil and gas extraction
  drilling oil and gas wells
  support activities for oil and gas operations

natural gas distribution (private)
natural gas distribution (public)
oil and gas pipeline and related structures construction
petroleum refineries
petroleum lubricating oil and grease manufacturing
asphalt paving, roofing, and saturated materials manufacturing
petroleum and petroleum products merchant wholesalers
pipeline transportation
gasoline stations with convenience stores
other gasoline stations
fuel dealers

In estimating indirect employment the study removed transactions between these industries in order to avoid double counting. Jobs were counted whether full-time or part-time and were not converted to FTEs.

The study provided direct employment estimates for oil and gas operations for the above industries (excluding capital expenditures that are allocated to the supplying sector), indirect and induced employment from supporting the sector's operations, and indirect and induced employment generated by capital expenditures, all for 2007. The results are shown in Box 10. The type II multiplier for operational jobs was 3.7, indicating the very strong backward linkages in the oil and gas sector. One half of these jobs were concentrated in the services sector.

Box 10: Direct, indirect, and induced employment in U.S. oil and natural gas industry in 2007

Direct job creation in oil and gas industries

Sub-sector	Employment
Oil and gas extraction	368,451
Drilling oil and gas wells	87,996
Support activities for oil and gas operations	205,662
Natural gas distribution (private)	108,900
Natural gas distribution (public)	8,654
Oil and gas pipeline and related structures construction	97,817
Petroleum refineries	70,410
Petroleum lubricating oil and grease manufacturing	9,543
Asphalt paving, roofing, and saturated materials manufacturing	26,387
Petroleum and petroleum products merchant wholesalers	103,472
Pipeline transportation	39,377
Gasoline stations (all)	905,803
Fuel dealers	90,817
Total	2,123,291

Indirect and induced job creation by supplying sector

	Operational impact	Capital impact
Agriculture	104,549	17,993
Mining	9,268	1,630
Utilities	22,523	3,749
Construction	207,528	13,395
Manufacturing	397,299	283,535
Wholesale and retail trade	892,854	281,908
Transportation and warehousing	206,629	69,863
Information	124,081	41,778
Finance, insurance, real estate, rental and leasing	708,422	120,482
Services	2,834,634	564,840
Other	187,359	19,771
Total	5,695,146	1,418,944

Source: PricewaterhouseCoopers. 2009.

Estimating the total employment created by alternative projects

In order to compare employment generated by alternative projects, a common metric has to be chosen. Examples include total GWh of electricity generated per year and the total expenditure on the project. The comparison on one metric would mean that the projects would usually not be directly comparable on an alternative metric. Two technologies generating the same amount of electricity would not cost the same amount, and conversely two projects costing the same would not generate the same amount of electricity. An additional complicating factor on the cost side is how the project is financed, and in particular the need for increasing revenue to balance public sector outlays (or lower tax receipts) to finance the project. Were a third metric, such as greenhouse gas emissions, to be added, projects would typically differ on two of the three metrics. The employment generated adds a further dimension for consideration. There can be trade-offs between these metrics and project design typically attempts to assess them on a common monetary metric. Employment is not conventionally taken as equally important as output or cost, but provides supplementary information for ranking projects by other criteria.

The study by Grover (2007) compared the targets of the Solar America Initiative (5–10 GW by 2015 and 70–100 GW by 2030) with the alternative of providing the same amount of electricity generation through new gas-fired plants. A number of important assumptions were made in order to make a direct comparison between these two scenarios. Based on load profile data and existing performance, solar PV was assumed to act as an alternative to gas. The capacity factor of solar PV plants was assumed to be 19 percent, reflecting experience elsewhere in the United States. For the project as a whole the average ELCC was assumed to be 60 percent—60 percent of installed solar PV capacity was assumed to be available during peak generation periods. Natural gas plants require power to be transmitted and losses of 7 percent were assumed. The size of the new natural gas plant was assumed to be 250 MW, with a heat rate declining to 6,333

British thermal units per kilowatt-hour by 2015. Solar PV was assumed to have an O&M cost of $35/kW in 2005, declining to $10.94/kW by 2030.

Solar PV was estimated to cost $3.5 billion per GW and the equivalent capacity of gas (600 MW) $402 million. To put these two scenarios on an equal footing, the difference of $3.1 billion was assumed to be spent by households following historical purchase patterns. The approach enables solar PV and gas to be compared directly, and it would also be possible to use the jobs created by the $3.1.billion spending as a measure of jobs that would be destroyed by an equivalent amount of increased taxes that would have to pay for the extra costs of solar PV relative to gas.

The costs of the two programs were entered into the IMPLAN IO model in order to generate the employment and incomes benefits of the programs. Impacts were estimated for construction spending assumed to be concentrated into a single year (2015), and O&M included both full-time and part-time jobs. Gross employment was that created by the solar PV program, while net employment subtracted from this the employment that would be created in the counterfactual (gas with extra household spending). Allowance was made for jobs lost by the closure of some gas plants under the solar PV scenario. Jobs are estimated just for a single year, so that the number of job-years created by O&M was underestimated. The results for the numbers of jobs in 2015 in the scenario installing 5 GW of solar PV by 2015 are shown in Box 11. The gross job employment numbers show construction as dominant with large multipliers. There were much fewer jobs in O&M. The position on net jobs was substantially different. On the direct construction side there would have been a net loss of jobs, while indirect and induced jobs were much reduced. O&M jobs were also many fewer, but still led to a positive net increase in jobs. The heavier job creation for the solar PV program suggests that construction programs tend to be more labor-intensive than the results of household spending, which is spread across a variety of items. The large difference between the gross number of jobs and net number of jobs indicates how important it is to take account of an appropriate counterfactual before assessing the gains to be made from any particular program.

Box 11: Job creation of a solar PV program to install 5GW by 2015, versus an equivalent gas program and balancing household expenditure in the United States

	Direct	Indirect	Induced	Total
Gross construction	11,060	15,590	22,720	49,370
Gross O&M	5,270	2,660	4,300	12,230
Gross total	16,330	18,250	27,020	61,600
Net construction	–5,410	6,050	8,131	8,770
Net O&M	4,310	1,130	1,310	6,810
Net total	–1,100	7,180	9,441	15,580

Source: Grover 2007.

Although the report did not carry out extensive sensitivity analysis, it is clear that the results could be sensitive to certain parameters. The assumption that the difference of $3.1 billion per GW of power generation capacity would all be spent by households is likely to over-estimate the number of jobs created in the benchmark case, thus understating the net job creation—if the government were to transfer this sum in reduced taxes or increased transfers (keeping the overall fiscal cost equal between the two alternatives when publicly funded), households would likely spend only a fraction of this sum and save the rest. The treatment of the solar PV capacity factor (19 percent) and the ELCC (60 percent) in the context of meeting peak demand is also crucial. A lower ELCC would require less spending on gas plants relative to solar PV plants, and a corresponding increase in the money allocated to the household sector with a further increase in employment and reduction in net jobs.

Although the two alternatives produce the same energy output, and cost the same, the gas and household spending combination clearly generates considerable household welfare that is not present with the more expensive renewable program. A full comparison between alternative programs would have to take such features into account.

A report prepared under the Renewable Energy Policy Project (REPP 2001) makes a comparison between different energy sources in terms of direct employment generated per MW of installed capacity over 10 years of plant operation. Differences in the costs of the technologies investigated were not taken into account. A distinctive feature of the study was the way in which employment was estimated from survey data that focused on each stage of manufacturing, installation, construction, and operation. The results for solar PV are shown in Box 12. The employment levels estimated are for direct jobs only, but these could be attached to multipliers from an IO table to generate indirect and induced employment totals. Similar surveys were carried out for a 37.5 MW wind facility, and for biomass co-firing from six different fuels. For biomass the employment in four areas was considered:

growing, harvesting, preparing
receiving, inspecting, storing, conveying to coal plant
transport
manufacture of a biomass feeder

It was initially assumed that employment was strictly proportional to scale, but the study discussed how to allow for trends in labor productivity for future biomass co-firing.

Box 12: Direct employment to manufacture, install, construct and operate a solar PV plant

Labor requirements per average MW of PV (in hours) based on a 2kW residential installation in U.S.

	Professional technical & managerial	Clerical & sales	Services	Processing	Machine trades	Benchwork	Structural work	Miscellaneous	Total
Glass	50			50	50			50	200
Plastics	50				250				300
Silicon	1,550	200	200	3,300	200	200			5,650
Cell manufacture	800			1,600		600	50	150	3,200
Module assembler	3,500			1,600		8,250	750	6,850	20,950
Wires	150				1,700				1,850
Inverters	750			1,000	1,000	1,000	1,000		4,750
Mounting frame	500	500			150	100	150	100	1,500
Systems integration	8,900	2,850							11,750
Distributor/contractor	1,500	1,500						1,000	4,000
Installer	2,500						8,000		10,500
Servicing[a]	5,000								5,000
Total	25,250	5,050	200	7,550	3,350	10,150	9,950	8,150	69,650
Total person years	12.9	2.6	0.1	3.9	1.7	5.2	5.1	4.2	35.5

Source: REPP 2001.
a. Servicing over 10 years.

To compare different technologies, corrections for capacity factors were built into the tables. The solar PV was assumed to have a capacity factor of 18 percent, wind 30 percent, and biomass co-firing 80 percent. On this basis, 1 MW of solar PV on average generated 35.5 direct jobs, 1 MW of wind generated 4.8 jobs, and 1 MW of biomass co-firing generated between 3.8 and 21.8 jobs depending on the feedstock. The study also made a comparison with conventional coal-fired plants. Because the study projected employment over the first 10 years of plant life, an important factor was the increased labor productivity of coal mining. Between 1988 and 1998 labor productivity had grown rapidly and it was assumed that this would continue until 2008, giving an increase by 19 percent over the total period. Using model plant data, the authors compared coal, wind, and solar PV in terms of their employment generated over a ten-year period per million dollars of investment. The comparison included mining and transporting the coal, building a coal-fired power station, and O&M. On this basis coal created about four jobs-years per million dollars, compared to nearly six job-years for wind and solar PV. This comparison did not provide information on the amount of electricity generated by each technology per million dollars of spending.

The study by APEC (2010) reviewed the potential for various liquid biofuels in the Asia-Pacific region, basing its analysis on established industries: ethanol from maize in the United States, ethanol from sugar cane in Brazil, biodiesel from palm oil in Malaysia, and biodiesel from soybean oil in the United States. Other studies calculating employment creation were reviewed, both for direct jobs and for direct and indirect jobs. These studies exhibited considerable variation even for the same fuel. The study then provided a standardized methodology, drawing on international experience in the four crops, to estimate employment generated per million liters a year of production. The methodology allowed for the agricultural activities (seeding, harvesting, and transportation) as well as for fuel production itself.

The method was based on a simple equation as shown in Box 13. The method assumed a reasonable size for the fuel manufacturing facility and took account of economies of scale where different-size facilities were considered. For each facility type of a specified scale, an expert value of numbers employed for O&M was included in the detailed section relating to employment generation, and numbers of FTE jobs generated for the various agricultural activities were calculated from international experience. These numbers were adjusted by labor costs to provide the costs of labor input. No allowance was made for jobs being switched from the cultivation of other crops.

Box 13: A suggested formula for calculating employment generated by the production of 100 million gallons of biofuels

Employment from a 100 million-gallon-a-year plant

= Plant output value / economy-wide output per person (a)

= Labor input costs × output value per unit of input value / GDP per employee (b)

= (Labor cost at refinery + labor cost of feedstock) × (refinery output × world price of output) / (input of feedstock × world price of feedstock) / GDP per employee. (c)

Source: APEC 2010.

There are two issues with the formulae used to calculate employment generation per unit output for the four feedstocks. First, by relating plant output to national output per worker, in order to scale employment to biofuel production output, it was assumed that labor intensity in the biofuels sector was equal to that of the average for the national economy. This assumption, also used by Álvarez, Jara, and Julián (2009), needs justification in any given economy. It is quite likely that the high agricultural content of biofuels may make it more labor-intensive than the rest of the economy (though wage rates may be relatively lower, meaning any relative change in total labor income will be smaller than the relative change in employment). Using the ratio of gross domestic product (GDP) to national employment implies that the total of direct, indirect, and induced employment is being estimated, since all are included within the single national aggregate. The second problem with the formulation was the transition that introduced input costs: the labor input cost was not equal to the value of input (as seen from the authors' own examples), so that equation (a) did not imply equation (c), that is, inserting the individual values into (c) would not generate the value of (a). Indeed, because the study provided the values of the components of (a) separately, these can be used to directly calculate the employment generated, and this turns out to be different from that based on (c).

Kammen, Kapadia, and Fripp (2004) and Wei, Patadia, and Kammen (2010) produced studies comparing employment created by different energy technologies. Both studies drew results from other reports rather than primary sources. The 2010 study carried out meta-analysis, averaging results from various sources. The meta-analysis approach has both strengths and weaknesses. By combining different studies for the same technology a more reliable estimate may be obtained by averaging out variations caused by inaccuracies in individual studies. However, such studies tend to be based on data from different dates, make different assumptions about how to measure employment (whether to include indirect and induced employment), correspond to different technological specifications as efficiency has tended change over time, and differ in plant size.

The studies lay an important emphasis on trying to standardize results as much as possible, and illustrate two important dimensions of doing so. First, they pointed out that CIM jobs are created for a short period while O&M jobs are created for the lifetime of the new plant. To obtain the total number of jobs created over the lifetime of the plant and per average year of the plant's lifetime, the different durations have to be allowed for. Second, they pointed out that where the target or comparison between alternative technologies is in terms of energy delivered, allowance must be made for the difference between the nameplate capacity (peak) and the average capacity that can be obtained from a given technology. Where the average capacity differs substantially between technologies, the plants with lower average capacity will need more peak capacity to deliver the same energy. Standardizing on output will produce larger employment for a lower capacity plant, but will at the same time tend to increase its capital and operating costs. The authors did not distinguish between the capacity factor (percentage of time that a plant is available) and the ELCC (measuring the percentage of time that the plant is available to meet demand for its output). A sample calculation of producing standardized estimates is given in appendix 4.

Wei, Patadia, and Kammen (2010) used their results to compare various generation technologies on the basis of direct employment generated per GWh (Box 14). The table indicates the large variations among technologies in capacity factors and plant life, both affecting the total number of job years created. Some of the technologies for which there were several studies to draw upon (some several years apart) showed a wide range of estimates, especially for solar PV, indicating the need for further work to be undertaken.

Box 14: Comparison of direct job years per GWh for alternative technologies in the United States

Range and average job years /year of plant life/GWh of alternative technologies

Technology	Capacity factor (%)	Plant duration	Minimum job years/GWH	Maximum job years/GWh	Average job years/GWh
Biomass	85	40	0.19	0.22	0.21
Geothermal	90	40	0.22	0.27	0.25
Landfill gas	85	40	0.32	1.12	0.72
Small hydro	55	40	—	—	0.27
Solar PV	20	25	0.23	1.42	0.87
Solar thermal	40	25	0.13	0.40	0.23
Wind	35	25	0.10	0.26	0.17
Carbon capture and storage	80	40	—	—	0.18
Nuclear	90	40	—	—	0.14
Coal	80	40	—	—	0.11
Natural gas	85	40	—	—	0.11
Energy efficiency	100	20	—	—	0.38

Source: Wei, Patadia, and Kammen. 2010.
Notes: — indicates that a single study was available and hence no range can be given.

Based on the estimates reported in their paper, the authors were able to forecast employment generation under different scenarios about the growth and share of renewable energy until 2030. The effects on total employment within the sector of different rates of improvements in the energy efficiency of the different technologies were also estimated.

Reflections on methods used to estimate employment generated by the energy sector

Before attempting to calculate the employment generated by an energy sector project, it is essential to define the object of the study. In assessing the impact on a local community of the jobs generated by a new project, it would be important to distinguish long-term employment measured in job-years (from O&M and the associated indirect and induced employment) from the temporary number of jobs created by CIM. If the choice is between alternative generation technologies, making comparisons based first on the need to compare alternatives that produce the same amount energy, and second on the need to hold constant the cost of investment, would be necessary. Projects with the largest associated employment may be more costly than those with lower employment for the same output, making allowance for the associated environmental costs where appropriate. As stressed earlier, seldom does it make sense to view employment as the only or the most important criterion for policy and project selection.

A second consideration in approaching the estimation of employment has to be the ease of use of the methodology. Although the great majority of studies reviewed have focused on the United States and to a lesser extent on EU members, some studies have shown that hybrid methods can work well. These involve estimating, possibly using local industry surveys, the direct costs of a project (including its labor component) and linking them to employment multipliers for indirect and induced employment derived from an IO table. Where no local IO table is available, importing multipliers from another country will give an improvement over a strategy of ignoring these employment components.

An issue raised by a number of studies is the accuracy of methods relying on IO tables. The most serious issue is the linking of the initial direct investment in a specific technology to the sectors in the IO table that are usually more broadly defined. Most countries that have an IO table will not have the fine detail available from IMPLAN for the U.S. economy, and have to make an allocation of expenditure between sectors. In the case of a highly aggregated model, the only option may be to allocate all expenditure to the energy sector itself. A second problem arises when the IO table is out of date and there are concerns that coefficients have changed.

Some of the studies reviewed have been able to provide important detail on the nature of the employment generated. The IO table itself generates estimates for every sector, and these can provide a first guide on the type of jobs that may be generated. More disaggregated estimates, based on information on local labor market wages and skills, have generated employment disaggregated by skill level. Labor market surveys can be used to provide suitable disaggregation for the types of direct employment that will be generated. Indirect and induced employment generated through multipliers will predict skill patterns that will be more typical of the aggregate economy.

Although this review of methodology has not attempted to derive quantitative results on the employment generated by various energy technologies, certain findings seem to be widespread. First, the type I and type II employment multipliers are well above unity, and often greater than 2, indicating that indirect and induced employment is larger than the direct employment of a project. This finding emphasizes how important it is to include indirect and induced employment in any calculation. Second, the duration of O&M linked employment is such that it is important for total job-years created. Accordingly, the length of the plant life assumed is important because the total number of job years will be proportional to it.

A finding of a different kind is that, even for a given technology, different studies have arrived at substantially different estimates of employment created. Such estimates are likely to be sensitive to the assumptions made, particularly with respect to the relation between the specifications of the project and the associated direct employment required. Economies of scale, changes in energy efficiency, and the degree of import content can all have substantial impacts on employment. Broader economic factors affecting labor supply and demand, the cost of capital, and the extent of crowding out by energy investments also need to be considered. The lesson of these findings is that not only are more detailed studies required, but that the specifications in any particular case will play an important role in determining the employment calculated.

Because of the variety of possible approaches to estimating the employment generated by an energy project, it can be useful to consider a number of questions about the project. The answers can provide guidance on how to proceed.

- Which concept(s) of employment is relevant for the exercise: direct, indirect or induced? If either of the latter two is needed, then type I or type II multipliers will be required.
- Is there project-level information that links spending to the costs of employment and the numbers directly employed by the project? In the absence of project data, could a survey be carried out of representative firms? If this would not be possible, either an employment multiplier from a suitable IO table, or information from other similar projects, will be required.
- Will the project require O&M? If there will be O&M activity, information on plant life will be required.
- Is an IO table with suitable sector disaggregation available? If so, then the employment and type I and II multipliers can be derived.
- If there is no IO table available for the country in question, is there one for a similar economy? Where this is available and a suitable level of sector disaggregation exists, multipliers can be imported to the country under study.
- If sector disaggregation is not sufficiently detailed, is it possible to spread direct expenditures across a number of sectors to represent the investment? Where accurate results are essential the unavailability of suitable IO coefficients implies that a survey must be undertaken in order to estimate the direct employment effects of the project.
- Is employment generated by skill level important? If the information on direct employment costs and numbers is disaggregated by skill and wage level, then direct employment can be categorized by skill level. To disaggregate indirect and induced employment by skill level similar information would be required for every sector.
- Is the project large relative to the size of the sector or economy? The larger the relative size of the project the more attention must be given to the limitations of using IO coefficients to project employment. The state of the labor market will limit the availability of surplus labor to be employed, any effect on wages and the price of the energy product will reduce demand and hence employment, and the financing of the project may lead to crowding out in other sectors.
- How are gross and net effects to be distinguished? The counterfactual needs to be specified, and its impacts on employment quantified in order that net employment creation can be estimated.

- How is the project to be financed, and what will be the associated impact of this financing on employment? Public financing will require offsetting fiscal action (increased taxes, reduced spending in other areas, etc.), and private sector financing may lead to higher costs and reduce demands for other goods, except in the case of energy efficiency where the impact of energy savings will be to increase income available for spending on other items, and hence employment.

Appendix 1: Comparing two projects: gross, net, and net-net job creation

Example 1. Projects A and B are alternatives for meeting a given output target. The employment created by these projects is 4 and 3 units, respectively. The opportunity-cost job losses brought about by the financing of these projects by the government are 2 and 2, respectively, because the financing requirements are the same. The job creation/destruction matrix is then as follows:

	Project A	Project B	Net project-to-project employment
Gross employment	4	3	+1
Opportunity cost employment	–2	–2	0
Net project-to-opportunity-cost employment	+2	+1	+1
			Net-net employment creation

Project A creates one more job, gross, than project B, resulting in a net project-to-project employment of one job. Project A also creates two more jobs than the opportunity cost of its financing destroys, leading to a net project-to-opportunity-cost effect of two jobs created. Similarly project B has a net project-to-opportunity-cost effect of one job creation. On a net-net basis project A creates one more job than project B when both are measured net of their opportunity costs.

Example 2. Both projects create gross numbers of jobs, but the opportunity costs of both destroy more jobs than are created. In addition the jobs destroyed are not equal because the financing implications of the two projects are different. The calculations are shown in the job creation/destruction matrix below:

	Project A	Project B	Net project to project employment
Gross employment	4	3	+1
Opportunity cost employment	–6	–4	-2
Net project to opportunity cost employment	–2	–1	–1
			Net-net employment creation

Project A creates one more direct job than project B, but the opportunity cost of its financing is larger than the gross jobs created by two jobs, and is larger than the opportunity cost of jobs lost to finance project B. As a result, project A destroys net-net one more job than project B.

These examples show that, in comparing two projects that have different financing implications and hence different job losses relative to opportunity costs, one project could create more jobs than another when the projects are examined in isolation, but could still result in a net loss of jobs once opportunity costs are taken into account. Both sets of comparisons are needed to make a full assessment.

Appendix 2: Derivation from input-output tables of direct, indirect, and induced employment effects, and backward and forward linkages

Direct, indirect, and induced effects

The standard IO model of an economy links the gross output of a sector to the final demand for that sector and to the intermediate demands made by other sectors for its output. This can be expressed as

$$X = A\,X + F, \tag{1}$$

where X is a vector of gross outputs of the N sectors of the economy, F is a vector of final demands for these sectors, and A is the N × N matrix of technical coefficients that indicate how much output from sector i is directly required to produce one unit in sector j.

The gross output is then related to final demand by equation 2 where the coefficient matrix B (Leontief inverse) measures the total amount of sector i that is required to be produced in order to satisfy the direct and indirect demands produced by one unit increase in the final demand for sector j:

$$X = (\,I - A\,)^{-1}\,F \equiv B\,F. \tag{2}$$

Equation 2 produces the type I multipliers linking direct and indirect outcomes to an initial change in final demand. To convert output figures into employment figures, a vector of employment levels per unit output is required (usually measured in FTE employment units) represented by W. The direct employment effect of a one unit increase in final demand for sector j would be denoted by W_j. One unit increase in the demand for sector j will generate direct and indirect employment as expressed in equation 3:

$$E_j = \sum_i W_i\ B_{ij}. \tag{3}$$

To allow for induced effects (from the consumption generated by the extra incomes from the direct and indirect effects), the IO matrix can be expanded to incorporate a vector of expenditures on each sector when income increases by one unit. This can allow for the fraction of these incomes that is paid in taxes or is saved. The calculation of the type II or extended matrix B is then linked to the augmented matrix A (Scottish Government 2011).

In practice IO tables are usually expressed in values so that coefficients measure the requirements in dollars on sector i when sector j increases its final demand by one dollar. In this case employment induced is also measured in dollars. National data on employment by sector provides a ratio between expenditure on labor and employment that allows the employment effects (direct, indirect, and induced) to be calculated.

Forward and backward linkages

The concepts of forward and backward sector linkages were formalized by Rasmussen (1956). The sum of the column *j* elements of matrix *B* is the total output from the whole system of sectors required for a unit increase in the output of the final demand for sector *j*:

$$\sum_i B_{ij} = B_{.j} \tag{4}$$

Normalization is carried out to compare a particular sector with other sectors:

$$U_{.j} = B_{.j} \, / \, [\, \sum_k B_{.k} \, / \, \mathrm{N} \,] \tag{5}$$

The backward linkage index measures how much a given sector (*j*) uses the direct and indirect outputs of all other sectors, relative to the average of all sectors. When the index is greater than unity, it draws more heavily on inputs than the average of other sectors and has a high (relative) backward linkage.

Similarly, the forward linkage is based on the sum of row elements in matrix *B*, which is the increase in the output of a given sector that would be required if all sectors faced a unit increase in final demand. It measures the importance of a given sector in the supply chains of the economy. It is normalized analogously to equation 5, and indicates its relative importance in supplying increases in output required to meet final demands.

The backward linkage starts with a unit increase of the sector in question and links this increase to the supply responses of all sectors, while the forward linkage starts with a unit increase in final demand for all sectors and relates these to the impact on a given supply sector.

Forward and backward linkages can also be defined in terms of employment demands by converting the elements of matrix *B* from output values to employment numbers through the *W* factors, and the wage bill to employment ratios.

A simplified example of use of IO tables to estimate employment supported by a sector

Input-output tables can be used to answer two related questions:

1. How many jobs are currently supported by a given sector?
2. If demand for the output of the sector changed by a certain amount, how many extra jobs would this create?

The example given below, based on an illustration given by New South Wales Treasury (2009) and on explanations in The Scottish Government (2011), illustrates the steps involved in making such calculations and is constructed to be of the simplest possible form to enable steps to be followed easily.

Step 1: The transactions table

The economy underlying the transactions table consists of two producing sectors (M and N) that supply goods to households (H) and the government (G). The economy is closed with no imports or exports. The factors of production are labor (L) and capital (C). Table 2 shows the values of all sales and purchases made by each sector in the economy. The final demands from sectors H and G are exogenous. The total value of all sales of the sectors is made up of the items in the corresponding rows. For example, sector M sells 200 to its own sector, 500 to sector N (both as inputs to their own production), 300 to households for final consumption, and nothing to the government sector, resulting in the total (gross) output of 1000. Columns denote purchases, so that sector M purchases 200 units from itself, 400 units from sector N, 200 units from labor, and 200 units from capital. Total purchases (inputs) are equal to 1,000 units. Every column total is equal to the corresponding row total. All entries are in monetary units. The transactions table is derived from official data for a particular year that ensures the balances between purchases and sales for each sector. This table is related to equation 1, in which the items of intermediate demand shown in the shaded area correspond to the elements of AX, the sum of H and G is final demand (F), and total output is the gross output (X).

Table 2: Transaction matrix for a closed two-sector economy

		Intermediate demand		**Final Demand**		**Total output**
	Sector	**M**	**N**	**H**	**G**	**TO**
Inputs	**M**	200	500	300	0	1,000
	N	400	100	200	250	950
	L	200	300	—	—	—
	C	200	50	—	—	—
Total input	—	1,000	950	—	—	—

Source: Authors.
Note: — = not applicable.

Step 2: The matrix of technical coefficients

From the data given in each column the technical coefficients are derived. These are defined as the ratio of the input from a particular type of supply to the total inputs utilized. For example, industry N uses 100 units of N out of a total input of 950, yielding a technical coefficient of 0.11 (Table 3).

Table 3: Matrix of technical coefficients

		Intermediate demand	
	Sector	**M**	**N**
Inputs	**M**	0.20	0.53
	N	0.40	0.11
	L	0.20	0.32
	C	0.20	0.05

Source: Authors' calculations.

The coefficients on labor indicate the amount of expenditure on labor that would be required per unit expenditure on goods M and N. The shaded area is the matrix *A* referred to in equation 1. The key for using IO tables for simulating the effects of changes in final expenditure is the assumption that, in the simplest case, the technical coefficients remain constant. This applies equally to simulating large or small changes, in which the demands for factors remain strictly proportional to output (no economies of scale), and to simulating changes in the future, in which no technical efficiency improvement or other factors change the coefficients.

The table illustrates the nature of indirect effects. An increase in demand for M by one unit (say from government) requires 0.2 more units of M, 0.40 units of N, 0.2 units of labor and 0.2 units of capital. However, the 0.2 extra units of M then require a further 0.04 (0.2 × 0.2) units of M, 0.08 units of N, 0.04 units of labor, and 0.04 units of capital. The extra demand for N also generates further demand for the four factors. In turn the extra demand for M and N generate yet more demands for the factors. At each stage the extra demand is substantially smaller than at the previous stage. The sum of these incremental demands provides the multipliers used in input output analysis.

Step 3: The Leontief inverse

Based on matrix *A* (shaded area in table 2) the matrix $I - A$ is formed, where *I* is the unit matrix (unity along the main diagonal and zero elsewhere). This matrix is then inverted to yield the Leontief matrix (*B*). All these calculations relate to the value of output. Table 4 and Table 5 provide the steps leading to the calculation of the Leontief inverse.

Table 4: The matrix $(I - A)$

Sector	M	N
M	0.80	–0.53
N	–0.40	0.89

Source: Authors' calculations.

Table 5: The Leontief inverse $(I - A)^{-1}$

Sector	M	N
M	1.77	1.04
N	0.79	1.58

Source: Authors' calculations.

An initial extra unit of final demand for M generates 1.77 total demand for M and 0.79 extra demand for N. Similarly, one unit final demand for N would generate 1.58 total extra demand for N and 1.04 extra demand for M. The initial increment in demand of one unit is termed the direct effect, while the total increase in demand, obtained from the Leontief inverse, is termed the direct and indirect effect. By difference, the indirect effect on the output of M following the unit increase in final demand for M is 0.77. Combining the direct and indirect effects on both sectors, following the initial increase in the demand for M, results in an economy wide increase of 2.56. The ratio of the economy-wide impact to the initial demand change is the type I multiplier effect.

These effects are summarized in Table 6. The type I output multiplier (shaded) for the effects on the economy as a whole is then 2.56. Similar calculations show that a unit increase in final demand for N results in an additional increase in output of 2.62.

Table 6: Direct and indirect effects on output from a unit increase in demand for sector M

Sector	Direct	Indirect	Direct+ indirect
M	1.00	0.77	1.77
N	0.00	0.79	0.79
Total economy	1.00	1.56	2.56

Source: Authors' calculations.

Step 4: Calculating direct and indirect employment factors

The transactions table and technical coefficients matrix refer to the value of labor used to produce output. For the purposes of the present study this needs to be converted into FTE jobs. The necessary information to make this link is not normally contained within an IO table, but has to be obtained from other sources. Census type data can provide the number of employees per sector, while wage and price surveys provide average wage rates. This illustration assumes that the average wage rates in the two sectors are 1.0 and 1.2 (measured in annual values to be consistent with the transactions table). This allows the number of jobs created per unit of output to be derived for each sector, corresponding to W above. Table 7 summarizes the employment position.

Table 7: Employment related to initial final demands

Sector	Wage bill	Wage rate	Employment	Jobs per unit output
M	200	1.0	200	0.20
N	300	1.2	250	0.26
Total	500	—	450	—

Source: Authors.
Note: — = not applicable.

The relation between a unit change in final demand for sector M and the corresponding changes in employment can be determined by combining results from Table 6 and Table 7. A one unit increase in demand for M leads to a 1 unit direct output effect from sector M, creating 0.2 jobs. It creates a total of 1.77 direct and indirect output of M corresponding to 0.35 jobs, and 0.79 units of N corresponding to 0.21 jobs. The total direct and indirect employment is then 0.56, of which 0.36 are indirect. This calculation, multiplying each total change in output generated by the job creation ratio for that sector, corresponds to equation 3. The results for unit increases in final demand for each sector are shown in Table 8. The type 1 multiplier for employment relates the total number of jobs created to the initial increase in demand. For sector M the multiplier is then 0.56.

Table 8: Employment effect for unit increases in demands for each sector

Sector	Direct effect	Indirect effect	Direct + indirect
M	0.20	0.36	0.56
N	0.26	0.37	0.63

Source: Authors' calculations.

Step 5: Calculating induced employment effects

The flow of extra incomes as a result of the extra employment creates a further multiplier effect. As a fraction of these incomes are spent of goods M and N (rather than saved or paid in taxes) demand rises further and the process continues as before. This extra output creates even more jobs and these result in a second multiplier process. The total number of jobs created, including these induced jobs, yields the type II multiplier.

For this calculation the initial technical matrix is augmented by an extra row and column, making household income endogenous, and the Leontief inverse is formed. The extra row at the bottom of the matrix is the wage bill per unit of the output of each sector, while the extra column is the fraction of a unit of extra income that would be spent on each good. Details of the procedure are given in Miller and Blair (1985). The type II multiplier is larger than the type I multiplier because the feedback to household income creates further demand and more jobs. Hanson (2010) explained the possibility of estimating a type III multiplier, allowing for the jobs created from the feedback from expenditure on goods from non-wage household income (received via capital in the form of dividends and interest) allowing for different tax and savings rates.

Step 6: Using the multiplier analysis

The foregoing sketch of the use of an IO table illustrates how to answer the two questions posed earlier. The number of jobs supported by a sector can be derived from the original transactions matrix, applying the wage rate factors to labor payment—giving 450 jobs as shown in Table 7. An alternative approach is to consider the number of jobs (direct and indirect) created by a unit increase in final demand, and then multiply these by the level of final demands in the sectors. Using Table 2 to identify the level of final demand and Table 8 for the employment multipliers produces the same total employment. The extra employment created by a given increase in final demand follows immediately from Table 8.

Appendix 3: Summary of recent studies that measure employment creation

Study	Focus of study	Counterfactual	Methodology	Comments	Ease of replication
REPP (2001)	Quantified employment generated in the United States per MW of capacity of • solar PV, • wind power, and • biomass co-firing, and per $ million expenditure for • solar PV, • wind power, and • coal.	Project by project. No consideration of fiscal costs and their employment implications.	Written and telephone surveys of renewable energy (RE) firms to estimate direct requirements for a standard plant. Biomass co-firing also used research-based data. Model plant data for coal. Full chain (including biomass collection, coal mining, and fuel transportation). Construction, and 10 years of O&M for all plants. Based on total person-years.	Surveys included 9 work functions by stage of manufacture/installation/ servicing. Discussed but did not quantify costs of biomass feeder. Discussed issues of trends in labor productivity. Made adjustment for capacity factors. No indirect or induced effects. No discussion of imports. Discussed issues of scale and representativeness of plant sizes chosen.	Methodology fully described for all fuels. Method dependent on survey approach for PV, wind, and biomass. Existing national data needed to estimate coal labor costs and employment using sector wages.
Heavner and Churchill (2002)	Compared employment created by alternative options in California for 500 MW of • wind power, • geothermal, • solar PV, • solar thermal, • landfill/ digester gas, and • natural gas.	Project by project. No accounting of opportunity costs differing between technologies and hence destruction of different associated jobs.	Drew on other studies for direct and indirect employment estimates by technology, distinguishing between CIM and O&M jobs. 30 years of plant life. Accounted for labor productivity gains over plant life.	Some primary sources used surveys and did not include indirect jobs. Wind was assumed to have a capacity factor of 30% but other forms of RE were at 100%. Gas-sector employment was based on estimates submitted by firms for planning permission, and included indirect and extraction/transportation jobs. No induced employment was included. No discussion of imports into state. All jobs within a sector are at same wage.	Study was dependent on primary studies for most of the RE estimates.
U.K. DTI (2004)	U.K.-based study designed to measure the current number of jobs supported by	No counterfactual. Assumed that declining supply costs would	Constructed supply chains for several forms of mature and emerging RE and surveyed firms in each segment to give labor and	The supply chain outlined does not seem as broad as IO links would be (for example, did not include energy,	Detailed model calculation given in appendix B. Sample survey relied on

Study	Focus of study	Counterfactual	Methodology	Comments	Ease of replication
	RE industry and to estimate the number of jobs generated by target future industry. Current RE jobs covered • onshore wind, • offshore wind, • biomass, • energy from waste, • landfill, • solar PV, • hydropower, and • solar thermal.	contribute to the achievement of the aspirational 2020 government target for the share of RE.	materials content for CIM and O&M. Labor costs adjusted by typical wages to give employment linked to output. Durations obtained from survey. Accounted for indirect jobs by supply chain, imports at each link, additional jobs from new exports, and induced jobs via multipliers taken from national accounts data.	transportation, or management) and indirect and induced jobs may be too low. No categorization of jobs created by skill level or by sector.	specifying the whole supply chain accurately before seeking information.
Kammen, Kapadia, and Fripp (2004)	Calculated employment per average MW for alternative scenarios in the United States to meet 20% of current U.S. demand through various mixtures of • biomass, • wind power, • solar PV, • coal, and • natural gas.	Project-by-project employment comparison.	Drew on results of three studies (including REPP 2001) based on direct employment effects. Accounted for capacity utilization and durations for CIM and O&M. Because of different plant lives, average employment per year of plant life was calculated. Results for different technologies were then weighted in the different generation mix scenarios.	No consideration of indirect or induced jobs, or of imports. Coefficients for employment creation are taken from other studies and remain limited by their assumptions. There was no discussion of different costs or jobs destroyed by financing one alternative rather than another.	A template was provided that makes it simple to compare different technologies.
German Federal Ministry for the Environment, Nature Conser-vation, and Nuclear Safety (2006)	Estimated gross and net employment in Germany created by a government-supported RE target policy. RE treated as a single sector.	Net employment that took into account the job losses within the energy sector as fuel switching is encouraged, and budget-driven job losses.	A mixture of survey-based information was used to augment an existing IO table with an inserted RE sector, generating direct and indirect employment. This in turn was linked to a macro-economic model to provide estimates of jobs lost through offsetting budget adjustments to	The study provided a comprehensive calculation of gross and net jobs, accounting for imports and for induced exports. It distinguished CIM from O&M jobs but did not discuss duration explicitly. It did not discuss the capacity factors of RE but the	The English summary is not sufficiently detailed to understand all the assumptions made or the exact methods utilized. There is a full version of the report in German.

Study	Focus of study	Counterfactual	Methodology	Comments	Ease of replication
			the support provided to the RE industry.	expansion plan was based on a formal model that should take varying capacity factors into account. It did not discuss induced employment as such, but the macro-economic link should provide an overall link between spending and employment. Employment gains through stimulated exports were important in the results.	
National Biofuels Task Team (2006)	Estimated net job creation of meeting targets for biofuels supply in South Africa.	A business-as-usual scenario.	Based on detailed analysis of direct employment related to output targets, linked to IO tables for indirect and induced employment multipliers. Feedstock production, processing, CIM, and O&M jobs were included. No distinction was made between full-time and part-time jobs. Accounted for jobs lost as conventional fuel use is reduced. Analyzed effects and viability of four feedstocks to meet E10 and B2 targets. Analyzed the fiscal effects of supporting the program through reduced taxation on biofuels.	Study assumed that all agricultural labor would come from the unemployed where new land was needed. Assumed that there was adequate land and water to support the extension. Did not consider job loss due to extra fiscal costs of the program.	A very detailed study covering the whole range of economic feasibility issues. Valuable for illustrating a methodology for a developing country seeking to support a new biofuels industry.
Hillebrand et al. (2006)	Analysis of employment effects of German RE program with generation mandates and compulsory price compensation..	Policy investigated is self-financing through price changes. Comparison is to a business-as-usual case with no RE mandate.	Complex series of models estimated employment from requirement to construct more RE plants, changes in other generation and transmission, tax implications, effects on prices and household expenditures from higher costs of generation.	The short time horizon of the program investigated (2006–2010) may truncate some of the employment effects. CIM jobs were not distinguished from O&M jobs.	Framework for analyzing a change in RE policy is wide ranging and provides important insights to employment dynamics. Models are not sufficiently detailed to make replication straightforward.
Grover (2007)	Estimated gross and	The equivalent	Based on IO model that	The counterfactual was	Requires IO table, and

Study	Focus of study	Counterfactual	Methodology	Comments	Ease of replication
	net job creation of program of specified PV capacity expansion in the United States.	average capacity of natural gas, and household spending equivalent to the extra costs of PV over gas.	determined wage share of direct, indirect, and induced employment. Took employment from wage information for sectors. Distinguished between CIM, O&M, and research and development (R&D) jobs. IO table accounted for indirect and induced employment arising from imports. Accounted for capacity factors and matching of PV availability with peaking gas use. The equalizing household expenditure in the place of budget support for PV expansion in the counterfactual created indirect and induced employment.	unusual. Both programs were assumed to result in same government expenditure; the lower-cost gas program would actually require less offsetting fiscal contraction. Viewed in this light, both programs appeared to be job-creating because they were not relative to fiscal opportunity costs.	details on PV expenditures to be entered. Wage rates are also required to convert wage bills in each sector to jobs.
Snead and Barta (2007)	Provided a static estimate of current employment supported by oil and gas industry in Oklahoma.	No counterfactual.	Estimated direct, indirect, and induced employment, accounting for imports into state, for production and drilling stages of oil and gas industry, based on state-level accounts and a regional IO table.	No consideration of mid-stream or downstream oil and gas activities, and hence capacity factors were not relevant. Because the study calculated the total number of jobs in a given year, issues of duration of jobs did not arise.	The methodology is not described in detail but the study provides a valuable breakdown of all direct inputs into production and drilling activities.
Roland-Holst (2008)	California-based study of employment created by effects of historical decrease in energy intensity of households and resulting switch of expenditure to other goods. Projections of future gains from further energy efficiency improvements.	National household energy intensity trend forms counterfactual.	A CGE model was used to estimate direct, indirect, and induced employment effects of a shift in household expenditure, resulting from energy efficiency savings, to other goods. This included jobs lost in the energy sector itself.	The method used a broad measure of energy efficiency rather than project type gains. Projections were linked to specific technologies and policies for efficiency.	Useful review of some other studies but gives only a very brief account of methodology, particularly focusing on trends in the structure of the economy over a long period and link to IO tables.

Study	Focus of study	Counterfactual	Methodology	Comments	Ease of replication
Pricewater-houseCoopers (2009)	Estimated total employment supported by all stages of oil and gas industries for a given year by state in the United States.	No counterfactual appropriate for employment at an actual period in time.	Included direct, indirect, and induced employment for all stages of supply chain (exploration through to retail). Jobs derived from sector employment data, including CIM and O&M. Used IO table to obtain employment multipliers.	No discussion of imports but likely to have been excluded by IO balances.	Very detailed state-based data, including indirect and induced jobs by sector. Broad discussion of sources and methodology.
Álvarez, Jara, and Julián (2009)	Estimated number of jobs created in Spain for wind power and solar PV over eight years.	The number of jobs that would have been created if subsidy to RE had been spent elsewhere in the economy.	Direct and indirect RE jobs were taken from a separate study. Counterfactual jobs were taken from private economy-wide ratio of average capital per worker relative to total cost of subsidy.	Did not distinguish between jobs and job-years despite aggregating over several years' worth of data. Assumed without justification that the cost of a job created by government spending was the average capital per worker (IO studies use value added as the total cost per job and calculate employment from the wage-bill divided by the wage rate). Working at economy level included induced jobs, so the ratio of jobs created to jobs lost due to forgone opportunity costs was not on an equal basis. Other comments made by Lantz and Tegen (2009).	This study relies on another study for crucial data on job creation without detailed explanation. The macroeconomic ratios for counterfactual are easy to apply but need justification.
Lantz and Tegen (2009)	Theoretical study providing critique of Álvarez, Jara, and Julián (2009).	The same counterfactual as Álvarez, Jara, and Julián.	Criticisms included the following: Average capital per job is not the cost to the government of employment creation. The capital per job for RE should not be compared to that for the economy at large but should be for energy replaced. The study ignored export potential and job creation of RE program. Subsidy-based calculations ignored induced jobs	Authors discussed the view that public sector spending via subsidies crowded out spending elsewhere. There was not sufficient clarity in the Spanish study on how opportunity-cost dollars would be financed—an increase in taxes generally would reduce demand and jobs in private sector. The argument by Lantz	—

Study	Focus of study	Counterfactual	Methodology	Comments	Ease of replication
			but capital-cost calculations included them. The estimations for the numbers of RE jobs were based on projections made in 2003 rather than actual.	and Tegen—that there would be crowding out only at full employment—is likely to refer just to attempts to boost RE employment without considering public sector offsetting fiscal contraction. The criticism that capital cost was not the cost of a job was not fully explained.	
Pollin, Heintz, and Garrett-Peltier (2009)	U.S.-based study of employment creation of spending a given amount on of RE and energy efficiency program including • building retrofits, • mass transit/freight rail, • smart grid, • wind power, • solar, and • biomass.	Counterfactual was to reduce spending by the same amount on oil and gas, and coal.	Based calculations of direct, indirect, and induced employment on IO table. Accounted for import content and also for average wages in different sectors to translate wage bills from IO into employment. Indicated in which of eight sectors new jobs would be created. Broke job creation into three skill levels by average wage.	Study compared expenditure—not output—equivalence, and hence RE programs may generate less energy than the fossil fuel comparators. No discussion of duration.	Provides detailed information on how job-skill calculation was carried out. Study required a census of population to relate skill levels to sectors. Provides detailed information on how induced employment can be calculated.
Pollin and Garrett-Peltier (2009)	U.S.-based study of stimulus based employment for 5 alternatives: • military, • clean energy, • health care, • education, and • tax cuts.	Project against project. Calculation of employment generated by tax cuts can be used to quantify job destruction from tax increases for counterfactual, accounting for government financing.	Same conceptual approach as Pollin, Heintz, and Garrett-Peltier (2009).	Ignored the duration of jobs. Clean energy results from Pollin, Heintz, and Garrett-Peltier (2009) aggregated into a single sector. Comparison between objectives was purely on expenditure; output metrics would be more difficult to define than in the case where energy alternatives were evaluated.	Useful extension of authors' previous study to provide basis for counterfactual.

Study	Focus of study	Counterfactual	Methodology	Comments	Ease of replication
Frauenhofer et al. (2009)	Estimation of employment effects of a RE target for 2020 in the European Union: • biogas, • biomass, • biowaste, • geothermal, • hydropower (small and large), • solar thermal, • wave, and • wind power (onshore and offshore).	Considered effects of financing program and raising energy prices to consumers against business-as-usual energy path.	Used a series of interlinked models: green-investment generator, IO, and a macroeconomic model, to estimate a full range of employment effects. Direct, indirect, and induced employment, together with substitution effects from higher energy prices, and budget effects from government spending offsets. O&M distinguished from CIM. Capacity and plant lives detailed. Placed an emphasis on export effects arising from first-mover advantages in RE.	A fully articulated model that tries to take into account all linkages and feedbacks. Valuable information on 27 country-level outcomes. The large number of results makes it more complicated to understand the main thrust of results.	Provides valuable data on specifications for standard RE plants and a full write-up of the complex modeling exercise. Nevertheless, would be very challenging to adapt this methodology to other cases on the basis of material provided.
Houser, Mohan, and Heilmayr (2009)	U.S.-based study of employment effects of stimulus spending on alternative RE and EE options: • household weatherization, • building retrofits, • green school construction, • production tax credits, • investment tax credits, • demonstration projects for carbon capture and storage, • cash for	Options were compared to savings on fossil fuels but not to opportunity costs of funding the program.	Direct, indirect, and induced jobs were calculated for one year of the stimulus using an IO model. No discussion of imports. Capacity factors were not considered. Some options were assumed to be accompanied by complementary private financing. Discussed how to model effect of spending on each program.	Not considering opportunity cost was a major drawback. No macroeconomic linkages. All jobs treated equally.	Relatively little detail on methodology or numbers for technical coefficients provided.

Study	Focus of study	Counterfactual	Methodology	Comments	Ease of replication
	clunkers, • hybrid tax credit, • battery R&D, • mass transit, • smart metering, and • transmission.				
UNEP SEF Alliance (2009)	Review of many studies estimating how many jobs currently exist or could be created in the clean energy sector in various countries.	No single counterfactual. Some studies provided project-to-project comparisons.	A review of a large number of studies without formal standardization. Discussion of issues of defining green jobs. Some studies cited also provided alternative projects (fossil fuels or other government spending) as a comparison.	The results from different studies were not strictly comparable because they had not been carried out on an equivalent basis but instead used a wide range of methodologies. Included material on the nature of jobs (by skill and training) for certain clean energy investments. Distinction between CIM and O&M jobs and treatment of capacity were not always clarified. Some studies relate to estimated jobs created by government spending without considering jobs lost elsewhere due to fiscal offsets.	Review of a wide range of studies and some non-U.S. material is valuable for providing information on many topics and types of clean energy. Some studies provided data on details of skills required and wages paid for typical RE company.
Morriss et al. (2009a, 2009b, and 2010)	Critique of methods used to measure and justify green job creation, mainly in the United States.	No counterfactual.	Detailed point-by-point analysis of possible weaknesses in estimating the number of green jobs, either in existence or potential. Many of these jobs in the energy sector.	Did not set out formal criteria or model for an ideal approach but outlined shortcomings of all approaches.	Two shorter versions of the paper provide less technical material and are more focused on lessons learned.
CH2MHILL (2009)	Eemployment to be created by a 75MW solar project in Kittitas County in the state of Washington in the United States.	No counterfactual.	Used project details and IO table adapted to county level to generate direct, indirect, and induced jobs for both CIM and O&M phases. Accounted for impacts of extra local taxes, inflows of workers, and for imports.	Did not distinguish job types by wage level or skill.	Valuable example of a small-scale project and the calculations that can be made in such a case.

Study	Focus of study	Counterfactual	Methodology	Comments	Ease of replication
Schwartz, Andres, and Dragoiu (2009)	Estimated effects of a given $1 billion stimulus spending on employment, including detailed calculations for energy projects, in South America, Central America, and the Caribbean.	Sector by sector, but did not consider effects of fiscal financing.	Provided IO-based direct employment estimates, accounting for imports. Also estimated indirect and induced employment. Discussed the macro-economic issues of crowding out. Divided workers into skilled and unskilled, paid at different wages, to generate total employment figures using the expenditure shares from IO table.	Focused on CIM jobs rather than O&M jobs, and did not discuss capacity since the policy focus was expenditure rather than output.	The use of a transition from a U.S.-based IO table to Latin American situation could be important for other studies. Detail on how expenditure on skilled and unskilled workers was obtained could be obtained from country-based reports to allow a disaggregated labor market response to be calculated.
EWEA (2009)	Surveyed economics of wind power including employment.	No counterfactual.	Provided estimates of direct jobs in European countries using survey approach. Provided information on types of jobs generated.	Did not distinguish between CIM and O&M jobs.	Useful references on the economics of wind power. Survey approach could be duplicated for employment in a given year.
Electrification Coalition (2010)	Modeled effects of policies to encourage uptake of electric vehicles in the United States.	A business-as-usual case with no policies implemented.	Detailed modeling translated policies into forecasts of vehicles purchased and miles traveled, accounting for some shift away from conventional vehicles. IO table is used to estimate employment effects. Macroeconomic effects of increased household income (lower fuel cost) and budget deficits and GDP growth rate calculated. Employment costs of financing policies were included.	The methodology was not fully articulated, making it difficult to evaluate strengths and weaknesses. No discussion of types of jobs (CIM versus O&M) or skills needed. Results seemed to rest largely on the assumption that extra household spending would be on more labor-intensive goods. No explicit discussion of extra electricity demand and its effects on fuel demand.	Useful illustration of a policy toward a specialized sub-sector, where a shift from conventional fuels is important. Not enough detail provided to easily replicate the method.
REN21 (2010)	Provided a snapshot of the state of the global RE industries, including	No counterfactual needed.	Based on secondary sources.	No discussion of various methodologies used in various studies, or consistency of assumptions utilized.	Source of reference material.

Study	Focus of study	Counterfactual	Methodology	Comments	Ease of replication
	employment.				
EREC and Greenpeace (2010)	Estimated global implications including employment of a set of pro-RE policies for the power sector.	A business-as-usual energy growth path derived from the International Energy Agency. Since the main instrument would be a carbon tax, there was no offsetting for fiscal costs of policy.	Methodology was based on Rutovitz and Usher (2010) and was presented only briefly. Calculated only direct jobs for both CIM and O&M. Accounted for imports to reallocate jobs between regions, trends in labor efficiency, and regional differences in employment required for a given investment. Provided global estimates for different fuels under alternative scenarios.	Did not consider indirect or induced employment. Did not deal with varying capacity factors or duration of plant. Since capacity total was taken from the International Energy Agency, it may be that varying capacity factors were implicitly taken into account.	Global calculations serve as a useful reference point. Summary of methodology gives a clear guide to approach.
Rutovitz and Usher (2010)	Detailed methodology for estimating global employment for EREC & Greenpeace (2010). Applied globally with regional breakdown. Separately analyzed • coal, • gas, oil, and diesel, • nuclear, • biomass, • hydropower, • wind power, • solar PV, • geothermal, • solar thermal, • ocean, and • combined heat and power.	No counterfactual.	Provided data from other primary sources on duration, CIM, O&M, and fuel procurement jobs per MW or GWh. Provided employment factors for coal for different regions/countries. Used regional adjustment factors depending on level of development, and adjusted for learning factors specific to each fuel.	No indirect or induced employment or discussion of peak versus average capacity. Method is best suited to average countries or regions rather than to any specific project in a given country.	Valuable data and clear methodology capable of being applied to other countries.
Hanson (2010)	Detailed explanation of the calculation of	No counterfactual.	Explained type I (direct + indirect) multiplier; type II multiplier	Illustrated by example of stimulus spending on the	Clear discussion of concepts and

Study	Focus of study	Counterfactual	Methodology	Comments	Ease of replication
	employment multiplier effects following an economic stimulus in the form of increased food assistance in the United States.		(adding induced); and type III multiplier (adding employment from spending out of unearned income generated by stimulus). Accounted for imports, labor productivity growth, income taxes, and savings. Distinguished between full-time and part-time jobs. Included a critique of the use of IO models.	Supplemental Nutrition Assistance Program (formerly food stamps) so no discussion of matters specifically relevant to energy sector.	methodology. Useful table indicating the relative importance of the different types of employment.
Pfeifenberger et al. (2010)	Estimated gross employment effects in a group of U.S. states in the Southwest Power Pool (SPP) for power transmission and wind farms.	No counterfactual. Project was entirely additional.	Used IMPLAN model to estimate direct, indirect, and induced employment from transmission. Considered alternative import scenarios. Used JEDI model for wind farms to generate initial investments and then used employment multipliers from IMPLAN. Specified duration and estimated total job-years generated.	No discussion of types of job, and no consideration of opportunity cost effects.	Requires access to equivalent to IMPLAN and JEDI models to reproduce this approach. A fuller account of some technical material is included in SPP (2010).
Wei, Patadia, and Kammen (2010).	Meta-study of gross direct employment generated by alternative generation technologies in the United States: • biomass, • geothermal, • landfill gas, • small hydropower, • solar PV, • solar thermal, • wind power, • carbon capture and storage,	Project-to-project employment calculations per average year over plant life per GWh generated.	Update of Kammen, Kapadia, and Fripp (2004). Averaged results over multiple studies for each technology. Direct employment from CIM, O&M, and fuel processing jobs was included, and durations and capacity factors were specified. Template developed to standardize results.	No consideration of indirect and induced jobs. Methodologies were taken from different studies and based over a range of years during which efficiency had improved, thus limiting comparability. No discussion of employment impacts of different financing costs to provide 1 GWh by different technologies or of imports.	Wide range of results placed in a standard format. Template is available from a website link provided.

Study	Focus of study	Counterfactual	Methodology	Comments	Ease of replication
	• nuclear, • coal, • natural gas, and • energy efficiency.				
European Climate Foundation (2010)	Estimated employment effects, and value of energy saving of building energy efficiency retrofit program in Hungary.	Business-as-usual rate of retrofitting compared to deeper alternatives.	Estimated direct, indirect, and induced employment effects over lifetime of program. Split jobs into three skill levels. Case studies were used to estimate direct costs and labor employment of initial intervention. These were linked to other sectors via IO tables. The spending from extra income generated by energy savings created further induced employment. Assumed that 80% of savings went back to pay for retrofitting while the rest was available for spending by households. Labor intensities of sector outputs were taken from national database. Accounted for improvement in retrofitting efficiency over time. Ran sensitivity analyses against alternative assumptions. Comparison of costs of program with energy savings indicated no net financing burden to the state.	Provided substantial institutional detail, several alternative retrofitting scenarios, the approach to calculation, and helpful references to other studies calculating employment impact of energy efficiency. Discussed issues of feedback on to wage levels of extra demand, and also rebound effect.	Authors indicated that they felt that parameters could not be imported from G7-type countries and hence needed to provide their own estimates of aspects of retrofitting program. Multipliers require an IO table.
APEC (2010)	U.S. maize ethanol, Brazilian sugar cane ethanol, Malaysian palm oil biodiesel, and U.S. soybean oil biodiesel. Developed a model plant formula for each fuel to estimate	No counterfactual.	Compared existing studies based on IO models for direct and indirect employment. Agricultural and biofuel manufacturing activities included (excluding employment from CIM in the biofuels sector).Constructed purpose-built models to estimate direct employment. Accounted for	Detailed calculations were not fully explained and confused labor input costs with total input costs to calculate employment generated. Spill over to other sectors was valued at average GDP per employee. Values based on particular cases, but can be	Very detailed presentation of spreadsheet methodology makes it easy to replicate, but methodology requires checking.

Study	Focus of study	Counterfactual	Methodology	Comments	Ease of replication
	employment generated on a standardized basis.		scale effects. Provided estimates for current employment in APEC countries. Discussed second-generation biofuels.	adapted.	
Labovitz School of Business and Economics (2010)	U.S.-based transmission project. Concentrated on employment from construction.	No counterfactual.	Estimates of direct employment and duration were provided by the construction consortium. Indirect and induced employment was generated by entering values into IMPLAN. Manufacturing-based employment and O&M jobs were not estimated. Imports were accounted for in IMPLAN. Very detailed results were presented for each sector, providing indirect and induced jobs.	Full-time and part-time jobs were not distinguished, and there was no discussion of the skill level of jobs generated.	The study provides extensive detail on how estimates were made and illustrates what could be achieved if a sufficiently disaggregated IO table is available.
ESMAP (2011)	Estimated employment creation of alternative growth paths of a CSP program in the Middle East and North Africa.	No counterfactual and just incremental supply.	Used surveys to establish employment characteristics and costs for local market supply potential. Linked to direct and indirect job creation through an IO table. Accounted for CIM and O&M jobs separately and for import content. One scenario accounted for employment for induced exports through first mover advantage.	Gross measure because impacts on substituted energy and of fiscal costs were not considered. Provided detailed market analysis of CSP potential in the region. No induced jobs or discussion of job skills required.	Methodology not fully articulated, but innovative in analyzing a market that is less developed than in other studies.

Study	Focus of study	Counterfactual	Methodology	Comments	Ease of replication
JEDI (2011)	Software site that calculates output, earnings, and employment generated in the United States by investment in an energy project for • wind power, • biofuels, • solar, • gas (to be added), and • coal (to be added).	No counterfactual and just the incremental effects of the investment itself.	Software requests certain key details (such as project size and location) and supplies default values for other parameters (that can be over-ridden). Multipliers for indirect and induced employment are supplied from the IMPLAN model. Import shares to region need to be specified. CIM and O&M effects are generated. Durations are specified in the model.	The gross employment figures do not distinguish types of employment by skill.	The software is available in a user-friendly form and many data entries are given default values that can be altered to suit local circumstances. This model has been widely used and not only for U.S. projects.
Verso (2011)	Estimated job creation of RE program between 2006 and 2009 in the United Kingdom.	Compared results to estimated employment created by alternative infrastructure spending or cuts in value added tax.	Derived total costs of RE program from detailed analysis of government activities to support RE. Employment effects calculated through an IO table. Allowance for imports made in sub-section dealing with Scotland. Allowed for the distinction between CIM job and O&M jobs, but did not convert to a job-year basis.	RE investment calculations did not appear to include indirect and induced jobs, while the alternatives did. The failure to consider the number of years jobs are generated for, and the number of years the tax cut would run, limit comparability of the results.	Useful analysis of total costs to the government of a RE program.

Appendix 4: Calculating average job-years over the life of a plant

The following calculation is based on estimation the direct employment per GWh per year generated by a sample coal fired plant.

Data are taken from REPP (2001) for a 200 MW coal plant and allow for manufacturing, O&M, and mining and transportation costs. Employment figures are calculated from industry data on wages and employment. No indirect or induced employment is calculated. Data are shown in a template taken from Wei, Patadia, and Kammen (2010).

Row	Component	Units	Calculation	Value
R1	Capacity factor	%	basic data	0.80
R2	Equipment lifetime	years	basic data	40
R3	CIM	job-years /MWp	basic data	8.50
R4	O&M	job-years /MWp/lifetime years	basic data	0.18
R5	Fuel extraction & processing	job-years /GWh/lifetime years	basic data	0.06
R6	Total jobs per peak megawatt for CIM	job-years /MWp/lifetime year	R3/R2	0.21
R7	Total jobs per peak MW for O&M + fuel processing	job-years /MWp/lifetime year	R4 + (R5×8,760/ 1,000×R1)	0.59
R8	Total jobs per average MW for CIM	job-years /MWa/lifetime year	R6/R1	0.27
R9	Total jobs per average MW for O&M + fuel processing	job-years /MWa/lifetime year	R7/R1	0.74
R10	Total jobs per GWh for CIM	job-years /GWh/lifetime year	R8/8,760× 1,000	0.03
R11	Total jobs per GWh for O&M + fuel processing	job-years /GWh/lifetime year	R9/8,760× 1,000	0.08
R12	Total jobs per GWh	job-years /GWh/lifetime year	R10 + R11	0.11

Source: Wei, Patadia, and Kammen 2010.
Notes: MWp = peak megawatts (nameplate capacity); MWa = average megawatts operation.

With a lifetime of 40 years, the average number of job-years created each year to produce 1 GWh of power, assuming an 80 percent capacity factor, is 0.11. Alternative generation technologies can be evaluated on the average annual job-years created using similar approaches. Following the methodology of REPP (2001) it would also be possible to compare projects on annual average costs per job per year.

References

Álvarez, G., R. Jara, and J. Julián. 2009. "Study of the Effects on Employment of Public Aid to Renewable Energy Sources." Universidad Rey Juan Carlos. http://www.juandemariana.org/pdf/090327-employment-public-aid-renewable.pdf

APEC (Asia-Pacific Economic Cooperation) Energy Working Group. 2010. "A Study of Employment Opportunities from Biofuels Production in APEC Economies." http://www.biofuels.apec.org/pdfs/ewg_2010_biofuels_employment.pdf

Bekhet, Hussain Ali. 2011. "Output, Income and Employment Multipliers in Malaysian Economy: Input-Output Approach." *International Business Research* 4(1): 208–223. http://www.ccsenet.org/journal/index.php/ibr/article/view/8811/6457

CH2MHILL. 2009. "Economic Impact Analysis for the Teanaway Solar Reserve, Kittitas County, Washington." http://teanawaysolarreserve.com/wp-content/uploads/2010/05/Teanaway_Economic_Impact_Analysis_10_07_09.pdf

Devarajan, S., D. Go, S. Robinson, and K. Thierfelder. 2009. "Tax Policy to Reduce Carbon Emissions in South Africa." Policy Research Working Paper WPS 4933. The World Bank: Washington, DC. http://www-wds.worldbank.org/external/default/WDSContentServer/IW3P/IB/2009/05/18/000158349_20090518093557/Rendered/PDF/WPS4933.pdf

Donald Vial Center on Employment in the Green Economy. 2011. "California Workforce Education & Training Needs Assessment: For Energy Efficiency, Distributed Generation, and Demand Response." http://www.engage360.com/index.php?option=com_k2&view=item&id=601%3Acalifornia-workforce-education--training-needs-assessment&lang=en

ECF (European Climate Foundation). 2010. "Employment Impacts of a Large-Scale Deep Building Energy Retrofit Programme in Hungary." http://3csep.ceu.hu/sites/default/files/field_attachment/project/node-6234/employment-impactsofenergyefficiencyretrofits.pdf

Ehrhardt-Martinez K., and J. Laitner. 2008. "The Size of the U.S. Energy Efficiency Market: Generating a More Complete Picture." American Council for an Energy-Efficient Economy. Report E083. http://www.aceee.org/research-report/e083

Electrification Coalition. 2010. "Economic Impact of the Electrification Roadmap.: http://www.electrificationcoalition.org/media/EC_ImpactReport.pdf

EREC (European Renewable Energy Council) and Greenpeace. 2010. *energy [r]evolution. A Sustainable World Energy Outlook*. 3rd edition.

http://www.energyblueprint.info/fileadmin/media/documents/2010/0910_gpi_E_R__full_report_10_lr.pdf

ESMAP (Energy Sector Management Assistance Program). 2004. "Energy Policies and the Mexican Economy." ESMAP technical paper 047. http://www.esmap.org/esmap/sites/esmap.org/files/FR279650_Mexico_Energy%20Policies%20and%20the%20Mexican%20Economy%20January%202004.pdf

ESMAP. 2011. "Middle East and North Africa Region Assessment of the Local Manufacturing Potential for Concentrated Solar Power (CSP) Projects." http://arabworld.worldbank.org/content/dam/awi/pdf/CSP_MENA__report_17_Jan2011.pdf

EWEA (European Wind Energy Association). 2009. "Wind—the Facts. Part III: The Economics of Wind Power." http://www.wind-energy-the-facts.org/

Frauenhofer ISI, Ecofys, Energy Economics Group, Rutter and Partner Socioeconomic Research and Consulting, LEI (Lithuanian Energy Institute), and SEURECO (Société Européenne d'Économie). 2009. "EmployRES: The impact of renewable energy policy on economic growth and employment in the European Union." European Commission Final Report TREN/D1/474/2006. http://ec.europa.eu/energy/renewables/studies/doc/renewables/2009_employ_res_report.pdf

Frondel, M., N. Ritter, C. Schmidt, and C. Vance. 2009. "Economic Impacts from the Promotion of Renewable Energy Technologies: the German Experience." Ruhr Economic Papers 156. http://repec.rwi-essen.de/files/REP_09_156.pdf

German Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety. 2006. "Renewable Energy: Employment Effects. Impact of the Expansion of Renewable Energy on the German Labour Market. Summary." http://www.bmu.de/files/pdfs/allgemein/application/pdf/employment_effects_061211.pdf German language full version at: www.erneuerbare-energien.de

Grover, S. 2007. "Energy, Economic, and Environmental Benefits of the Solar America Initiative." National Renewable Energy Laboratory. NREL/SR-640-41998. http://www.nrel.gov/docs/fy07osti/41998.pdf

Hanson, K. 2010. "The Food Assistance National Input-Output Multiplier (FANIOM) Model and Stimulus Effects of SNAP." Economic Research Report 103, U.S. Department of Agriculture. http://www.ers.usda.gov/Publications/ERR103/ERR103.pdf

Heavner, B. and S. Churchill. 2002. "Renewables Work: Job Growth from Renewable Energy Development in California." CALPIRG Charitable Trust.

http://www.environmentcalifornia.org/uploads/30/5d/305d111e53107a586d1986d195db30bb/Renewables_Work.pdf

Herig, C. 2001. "Using Photovoltaics to Preserve California's Electricity Capacity Reserves." http://www.nrel.gov/docs/fy01osti/31179.pdf

Hillebrand, B., H. Buttermann, J. Behringer, and M. Bleuel. 2006. "The expansion of renewable energies and employment effects in Germany." *Energy Policy* 34(18): 3484-94.

Houser, T., S. Mohan, and R. Heilmayr. 2009. "A Green Global Recovery? Assessing US Economic Stimulus and the Prospects for International Coordination." Peterson Institute for International Economics and World Resources Institute. PB09-3. http://pdf.wri.org/green_global_recovery.pdf

JEDI (Job and Economic Development Impact model). 2011. National Renewable Energy Laboratory. http://www.nrel.gov/analysis/jedi/about_jedi.html

Kammen, D., K. Kapadia, and M. Fripp. 2004 (revised 2006). "Putting Renewables to Work: How Many Jobs Can the Clean Energy Industry Generate?" Report of the Renewable and Appropriate Energy Laboratory. http://www.globalurban.org/Putting_Renewables_to_Work.pdf\

Labovitz School of Business and Economics. 2010. "The Economic Impact of Constructing Five Electric Power Lines in Minnesota, North Dakota, South Dakota, and Wisconsin." http://nocapx2020.info/wp-content/uploads/2010/11/capx-labovitz.pdf

Lantz, E. and S. Tegen. 2009. "NREL Response to the Report *Study of the Effects on Employment of Public Aid to Renewable Energy Sources* from King Juan Carlos University (Spain)." National Renewable Energy Laboratory: White paper NREL/TP-6A2-46261. http://www.nrel.gov/docs/fy09osti/46261.pdf

Miller, R., and P. Blair. 1985. *Input-Output Analysis: Foundations and Extensions*. Englewood Cliffs, New Jersey. Prentice-Hall.

Morriss, A., W. Bogart, A. Dorchak, and R. Meiners. 2009a. "Green Jobs Myths". University of Illinois Law and Economics Research Paper Series: LE09-001. http://www.instituteforenergyresearch.org/wp-content/uploads/2009/03/morriss-green-jobs-myths.pdf

———. 2009b. "7 Myths About Green Jobs." PERC Policy Series: 44. http://www.perc.org/files/ps44.pdf

———. 2010. "Seven Myths About Green Jobs." International Policy Network. http://www.policynetwork.net/sites/default/files/7_Myths_About_Green_Jobs.pdf

National Biofuels Task Team. 2006. "An Investigation into the Feasibility of Establishing a Biofuels Industry in the Republic of South Africa." http://www.cityenergy.org.za/files/transport/resources/biofuels/bio_feasible_study.pdf

NEI (Nuclear Energy Institute). 2009. "New Nuclear Plants: An Engine for Job Creation, Economic Growth." http://www.nei.org/resourcesandstats/documentlibrary/newplants/whitepaper/new-nuclear-plants-an-engine-for-job-creation-economic-growth

New South Wales Treasury. 2009. "Employment support estimates - methodological framework." TRP 09-3.

Pfeifenberger, J., J. Chang, D. Hou, and K. Madjarov. 2010. "Job and Economic Benefits of Transmission and Wind Generation Investments in the SPP Region." The Brattle Group. http://www.brattle.com/_documents/UploadLibrary/Upload859.pdf

Pollin, Robert and Heidi Garrett-Peltier. 2009. "The U.S. Employment Effects of Military and Domestic Spending Priorities: An Updated Analysis." Political Economy Research Institute, University of Massachusetts, Amherst. http://www.peri.umass.edu/fileadmin/pdf/published_study/spending_priorities_PERI.pdf

Pollin, R., J. Heintz, and H. Garrett-Peltier. 2009. "The Economic Benefits of Investing in Clean Energy. How the economic stimulus program and new legislation can boost U.S. economic growth and employment." Political Economy Research Institute, University of Massachusetts, Amherst. http://www.peri.umass.edu/236/hash/cb09819d9c97f255620591728706c85f/publication/350/

PricewaterhouseCoopers. 2009. "The Economic Impacts of the Oil and Natural Gas Industry on the U.S. Economy: Employment, Labor Income and Value Added." Prepared for the American Petroleum Institute. http://www.api.org/Newsroom/upload/Industry_Economic_Contributions_Report.pdf

Rasmussen, P. 1956. *Studies in Intersectoral Relations.* Amsterdam: North Holland.

REN21 (Renewable Energy Policy Network for the 21st Century). 2010. "Renewables 2010: Global Status Report." http://www.ren21.net/Portals/97/documents/GSR/REN21_GSR_2010_full_revised%20Sept2010.pdf

REPP (Renewable Energy Policy Project). 2001. "The Work that Goes into Renewable Energy." *Research Report 13*. http://www.repp.org/articles/static/1/binaries/LABOR_FINAL_REV.pdf

Roland-Holst, D. 2008. *Climate Action, Energy Efficiency, and Job Creation in California*. Center for Energy, Resources, and Economic Sustainability, University of California, Berkeley. http://www.irle.berkeley.edu/vial/publications/CAEfficiency_Jobs_DRH080901.pdf

Roland-Holst, D. 2010. "Real Incomes, Employment, and California Climate Policy." Research Paper 1007241, Center for Energy, Resources, and Economic Sustainability. University of California: Berkeley. http://www.next10.org/next10/pdf/trading/Roland_Holst_Final.pdf

Rutovitz, J., and J. Usher. 2010. "Methodology for Calculating Energy Sector Jobs." Institute for Sustainable Futures. http://www.isf.uts.edu.au/publications/rutovitzusher2010jobsmethodology.pdf

Schwartz, J., L. Andres, and G Dragoiu. 2009. "Crisis in Latin America: Infrastructure Investment, Employment, and the Expectations of Stimulus." *Policy Research Working Paper* 5009. The World Bank: Washington, DC.

Snead, M. and S. Barta. 2007. "The Economic Impact of Oil and Gas Production and Drilling on the Oklahoma Economy." Oklahoma Energy Resources Board. http://www.oerb.com/Portals/0/docs/State%20Oil%20Gas%20Impact%20Draft%2020080916.pdf

SPP (Southeast Power Pool). 2010. *SPP Priority Projects Phase II Report.* http://www.spp.org/publications/Priority%20Projects%20Phase%20II%20Report.pdf

Strand, J. and M. Toman. 2010. "Green Stimulus," Economic Recovery, and Long-Term Sustainable Development. Policy Research Working Paper 5163, World Bank, Washington, DC.

Scottish Government. 2011. "Input output introduction." http://www.scotland.gov.uk/Topics/Statistics/Browse/Economy/Input-Output

U.K. DTI (Department of Trade and Industry). 2004. "Renewable Supply Chain Gap Analysis: Summary Report." http://webarchive.nationalarchives.gov.uk/+/http://www.berr.gov.uk/files/file15401.pdf

UNEP (United Nations Environment Programme). 2008. *Green Jobs: Towards Decent Work in a Sustainable, Low-Carbon World.* Nairobi. http://www.unep.org/labour_environment/PDFs/Greenjobs/UNEP-Green-Jobs-Report.pdf

UNEP (United Nations Environment Programme). 2009. "Why Clean Energy Public Investment Makes Economic Sense – the Evidence Base." Sustainable Energy Finance Initiative Public finance Alliance (SEF Alliance). http://www.unep.org/pdf/dtie/WhyCleanEnergyPublicInvestment.pdf

Verso Economics. 2011. "Worth the Candle? The Economic Impact of Renewable Energy Policy in Scotland and the UK."

Wei, M, S. Patadia, and D. Kammen. 2010. "Putting Renewables and Energy Efficiency to Work: How Many Jobs can the Clean Energy Industry Generate in the US?" *Energy Policy* 38(2): 919–931.

World Bank. 2010. "Subsidies in the Energy Sector: An Overview." Background paper for the World Bank Group Energy Sector Strategy. http://siteresources.worldbank.org/EXTESC/Resources/Subsidy_background_paper.pdf