9-2010

The Employment Impacts of Economy-wide Investments in Renewable Energy and Energy Efficiency

Heidi Garrett-Peltier
University of Massachusetts - Amherst, hpeltier@econs.umass.edu

THE EMPLOYMENT IMPACTS OF ECONOMY-WIDE INVESTMENTS IN RENEWABLE ENERGY AND ENERGY EFFICIENCY

A Dissertation Presented

by

HEIDI GARRETT-PELTIER

Submitted to the Graduate School of the
University of Massachusetts Amherst in partial fulfillment
of the requirements for the degree of

DOCTOR OF PHILOSOPHY

September 2010

Economics

THE EMPLOYMENT IMPACTS OF ECONOMY-WIDE INVESTMENTS IN RENEWABLE ENERGY AND ENERGY EFFICIENCY

A Dissertation Presented

by

HEIDI GARRETT-PELTIER

Approved as to style and content by:

____
Robert Pollin, Chair

____
Michael Ash, Member

____
James Heintz, Member

____
Stephanie Luce, Member

____
Gerald Epstein, Department Chair
Economics

ACKNOWLEDGEMENTS

I would like to extend my sincere appreciation to my committee for their involvement and commitment in this process. I am grateful to my committee chair, Bob Pollin, for his guidance, encouragement, mentoring, and kindness throughout the writing of this dissertation. I thank each of my committee members for the unique role that each played: James Heintz for his wisdom and patience as he helped me work through some of the intricacies of input-output modeling; Michael Ash for his insistence that I relate my work to the broader field of climate change and also for his technical advice; and Stephanie Luce for her guidance as I developed, conducted, and evaluated the survey.

I am grateful to the Department of Economics and to the Political Economy Research Institute for providing the funding, education, inspiration, and fertile intellectual atmosphere that enabled me to complete this work. I thank the members of the Environmental Working Group for their feedback at various points throughout this process. I also thank my survey team for their persistence and hard work in making phone calls and emailing hundreds of contacts.

Finally, I wish to thank my parents, Michele and Michael, and my wife, Graysen, for their enduring love and support.

ABSTRACT

THE EMPLOYMENT IMPACTS OF ECONOMY-WIDE INVESTMENTS IN RENEWABLE ENERGY AND ENERGY EFFICIENCY

SEPTEMBER 2010

HEIDI GARRETT-PELTIER, B.A., UNIVERSITY OF CONNECTICUT STORRS

M.A., UNIVERSITY OF MASSACHUSETTS AMHERST

Ph.D., UNIVERSITY OF MASSACHUSETTS AMHERST

Directed by: Professor Robert Pollin

This dissertation examines the employment impacts of investments in renewable energy and energy efficiency in the U.S. A broad expansion of the use of renewable energy in place of carbon-based energy, in addition to investments in energy efficiency, comprise a prominent strategy to slow or reverse the effects of anthropogenic climate change.

This study first explores the literature on the employment impacts of these investments. This literature to date consists mainly of input-output (I-O) studies or case studies of renewable energy and energy efficiency (REEE). Researchers are constrained, however, by their ability to use the I-O model to study REEE, since currently industrial codes do not recognize this industry as such. I develop and present two methods to use the I-O framework to overcome this constraint: the synthetic and integrated approaches. In the former, I proxy the REEE industry by creating a vector of final demand based on the industrial spending patterns of REEE firms as found in the secondary literature. In the integrated approach, I collect primary data through a nationwide survey of REEE firms and integrate these data into the existing I-O tables to explicitly identify the REEE industry and estimate the employment impacts resulting from both upstream and downstream linkages with other industries.

The size of the REEE employment multiplier is sensitive to the choice of method, and is higher using the synthetic approach than using the integrated approach. I find that using both methods, the employment level per $1 million demand is approximately three times greater for the REEE industry than for fossil fuel (FF) industries. This implies that a shift to clean energy will result in positive net employment impacts. The positive effects stem mainly from the higher labor intensity of REEE in relation to FF, as well as from higher domestic content and lower average wages. The findings suggest that as we transition away from a carbon-based energy system to more sustainable and low-carbon energy sources, approximately three jobs will be created in clean energy sectors for each job lost in the fossil fuel sector.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure Page

LIST OF ABBREVIATIONS

ACEEE	American Council for an Energy-Efficient Economy
AEO	Annual Energy Outlook
BEA	Bureau of Economic Analysis
BLS	Bureau of Labor Statistics
BTU	British Thermal Unit
CCS	Carbon Capture and Sequestration
CCSP	Climate Change Science Program
CGE	Computable General Equilibrium
CO_2	Carbon dioxide
CO_2e	Carbon-equivalent emissions
DOE	Department of Energy
EIA	Energy Information Administration
EWEA	European Wind Energy Association
FTE	Full-time Equivalent
GDP	Gross Domestic Product
GHG	Greenhouse Gas
Gt	Gigaton
IAM	Integrated Assessment Model
IEA	International Energy Agency
I-O	Input-Output
IPCC	Intergovernmental Panel on Climate Change
kWh	Kilowatt hours
LIFT	Longterm Interindustry Forecasting Tool

MW	Megawatt
Mwa	Average Megawatt
NAICS	North American Industrial Classification System
NASA	National Aeronautics and Space Administration
PERI	Political Economy Research Institute
PPI	Producer Price Index
ppmv	parts per million volume
pv	Photovoltaic
REEE	Renewable Energy and Energy Efficiency
REPP	Renewable Energy and Policy Project
RPS	Renewable Portfolio Standard
SAM	Social Accounting Matrix
TPG	The Perryman Group

CHAPTER 1

INTRODUCTION

The threat of climate change has recently become a reality in the public mind. An abundance of scientific evidence – from the *Stern Review* to various reports by the Intergovernmental Panel on Climate Change – has shown that carbon emissions threaten our ecosystem and may cause irreversible and devastating impacts to the planet and our way of life (Stern, 2007), (Schneider, et al., 2007). In the face of such evidence, the need for an energy transition has become clear. To reduce carbon emissions, it is imperative to reduce our consumption of freely-emitting fossil fuels, the primary contributor of these emissions. This can happen through three channels – replacing fossil fuel consumption with energy consumption from low-carbon energy sources such as wind, solar, biomass, and nuclear power; capturing the carbon that is emitted from the burning of fossil fuels and storing it ("carbon capture and storage", or CCS)[1]; and increasing energy efficiency and conservation so that we reduce our overall level of demand for primary energy.

Until recently, this pro-environment transition was touted as bad for the economy. Now, however, the tide seems to be turning, and "green growth" is increasingly advocated as a way to create more jobs while increasing environmental sustainability. A report issued by McKinsey & Company, a worldwide consulting firm who in recent years

[1] CCS is not yet a commercially available technology, and assumptions on the timing and cost of CCS technology vary widely. In this dissertation, I will not explore investment or employment in this fledgling technology. However, many climate models consider CCS to be an important strategy for reduced emissions. See, for example, (Clarke et al, 2007), (Paltsev et al, 2009), and (Fawcett et al, 2009).

has become a leader in climate change policy analysis, refers to this as the “carbon productivity challenge” (McKinsey Global Institute, 2008). "Carbon productivity" is the amount of GDP produced per unit of carbon equivalent emissions (CO_2e). It is a useful concept for considering climate change mitigation in tandem with economic growth. As the authors point out, there is "agreement approaching consensus that any successful program of action on climate change must support two objectives - stabilizing atmospheric greenhouse gases and maintaining economic growth" (p 7) and that to obtain both objectives we need to drastically increase our carbon productivity.

In response to this rising public consciousness in support of green growth, there is a growing body of literature examining the economic effects of climate change mitigation, to which we will turn below. While many studies focus on the global impacts on GDP of action or inaction, other studies take a more targeted approach and examine the effects of national and regional strategies. Within this, we find studies addressing the employment impacts of climate change action, including investments in the renewable energy and energy efficiency (REEE) industry. If we shift from a fossil-fuel-based economy to one in which we use energy more efficiently and generate more power from renewable sources, what are the economic impacts? Which industries will gain from this energy transition, and which will lose? The obvious answer is that coal, oil and natural gas will lose while solar, wind, biomass, and other renewables gain. However, the picture is more complicated as each of these industries buys and sells goods and services from other industries in the economy. Thus we need to examine inter-industry relationships and employment patterns across industries in order to determine economy-wide employment impacts of a clean-energy transition.

In this dissertation, I will contribute to the literature on the employment impacts of investments in renewable energy and energy efficiency. I will explore the current state of this literature, then expand the methodology that has been used thus far and incorporate new data on REEE firms in the U.S. that I collected through an extensive survey process. I will present the results of various estimation methods using primary and secondary data.

The remainder of this dissertation is organized as follows. In Chapter 2 I first review the growing literature on the employment impacts of REEE investments. We will see that to date, researchers have been constrained in their ability to analyze the REEE industry due to data limitations. Nonetheless, a number of studies have been conducted using input-output modeling, case studies, and interviews, to gauge the employment effects of investments in REEE. Across the board, these studies have found that a shift from fossil fuels to REEE will engender positive employment effects. In Chapter 3 I will then discuss the input-output model, commonly used to estimate REEE employment impacts, and will create 'synthetic industries' which allow us to use the existing input-output tables in the absence of REEE-specific data. To overcome this limitation with currently available public data, I conducted an extensive survey of REEE firms throughout the U.S. I discuss the survey process and results in Chapter 4, and then in Chapter 5 present the methodology for integrating the survey results into existing input-output tables. This methodology is an innovation in the REEE literature and allows us to identify the REEE industry within the I-O tables and to estimate REEE employment in a manner consistent with employment in other industries. In Chapter 6 I then present the employment estimation results of these alternative methods. I also perform robustness tests and compare my results to each other and to estimates published by other researchers. We will see that by all measures, investments in REEE will generate positive employment impacts, even after we consider job losses in fossil fuels. Finally Chapter 7 contains concluding remarks.

In the remainder of this introduction I offer some background on the climate change debate as well as current and projected levels of renewable energy, energy efficiency, and global emissions.

Background on Climate Change, Renewable Energy and Energy Efficiency

The Threat of Climate Change

There is now an abundance of scientific evidence that we are currently experiencing anthropogenic (human-caused) climate change, and that carbon emissions are primarily to blame for global warming and other extreme weather events. The Environmental Protection Agency writes that:

> If greenhouse gases continue to increase, climate models predict that the average temperature at the Earth's surface could increase from 3.2 to 7.2ºF above 1990 levels by the end of this century. Scientists are certain that human activities are changing the composition of the atmosphere, and that increasing the concentration of greenhouse gases will change the planet's climate. But they are not sure by how much it will change, at what rate it will change, or what the exact effects will be.[2]

The Intergovernmental Panel on Climate Change, convened by the United Nations Environment Programme and the World Meteorological Organization, is a body of thousands of scientists worldwide who have reviewed hundreds of scientific, technical,

[2] EPA, accessed 4/8/08 at http://www.epa.gov/climatechange/basicinfo.html

and socio-economic studies of climate change. The results of the most recent completed assessment by the IPCC, the Fourth Assessment, were published in 2007. IPCC scientists found that "warming of the climate system is unequivocal" and that "Global greenhouse gas emissions due to human activities have grown since pre-industrial times, with an increase of 70% between 1970 and 2004" (IPCC, 2007, p. 30-36). Carbon dioxide is the most important source of anthropogenic greenhouse gas emissions, and its annual emissions grew by about 80% between 1970 and 2004, primarily from the use of fossil fuels (p. 36). While global energy intensity fell over the period, both population and income grew globally, resulting in overall growth in greenhouse gas (GHG) emissions. Global atmospheric concentration of CO_2, a measure commonly used in the literature to gauge the level and change of carbon dioxide, increased from a pre-industrial value of about 280 parts per million volume to 379ppmv in 2005 (IPCC, 2007, p. 37)."

While the precise implications for human welfare cannot be determined, various models predict a range of probable outcomes that increase in severity as the Earth's surface increases in temperature. For example, a team of scientists who form Working Group II of the IPCC have cataloged temperature-specific outcomes for humans as well as the rest of the eco-system (Parry, et al., 2007). They show that for global temperature rises of 3-5 degrees, risks (that are unevenly distributed) include such things as water shortages, coastal flooding, increased risk of malaria in some areas, reductions in crop yields, more extreme weather events, increased extinction of certain species, increased conflicts resulting from food and water shortages as well as changing migration patterns, and more severe market losses in low-altitude areas. The U.S. National Aeronautics and Space Administration (NASA) writes that "global climate change has already had observable effects on the environment" including glacial melting, changing plant and animal ranges, and trees flowering sooner, and that "the potential future effects of global climate change include more frequent wildfires, longer periods of drought in some regions and an increase in the number, duration and intensity of tropical storms."[3]

Economists, scientists and others have suggested that in order to prevent truly devastating consequences, we must act not only to halt any increase in our carbon emissions but also to reverse the rising trend and to lower emissions to below their 1990 levels. The policy recommendations for the speed and magnitude of the necessary changes vary among studies. On one end of the spectrum, the recommendations of Nicholas Stern are for "strong, early action" to stop and reverse any increase in emissions (Stern, 2007). Other the other end of the spectrum is William Nordhaus, who advocates a gradual policy ramp as the most economically efficient response to climate change, with slow and small steps now, gradually increasing in scope over the course of the century (Nordhaus, 2008). James Hansen of NASA as well as Rajendra Pachauri (head of the IPCC) support the Stern recommendations, which are to keep atmospheric concentrations of carbon dioxide to 385ppm or less, even to lower them to 350ppm (which would involve 'negative emissions' through strategies such as reforestation). At the heart of the issue of whether to act immediately or to follow a gradual 'policy ramp' are two factors: the discount rate and the level of climate sensitivity[4]. Both factors are chosen by the modeler, rather than being results of the model, and therefore changing an assumption

[3] http://climate.nasa.gov/effects/ accessed 4/20/2010

[4] The discount rate includes both the pure rate of time preference as well as a rate of return on capital. Climate sensitivity refers to the increase in temperature that results from a doubling of carbon dioxide emissions.

about either factor will change the policy prescription. A low discount rate combined with a higher level of climate sensitivity (greater temperature increases, which in turn cause greater damages) will lead to recommendations for immediate action, as promoted by Stern. Nordhaus, on the other hand, uses a higher discount rate and lower level of climate sensitivity, resulting in the call for more gradual action. Frank Ackerman and others have shown that by using the Nordhaus model (DICE-2007) and changing these assumptions, even this model recommends immediate and drastic action (Ackerman, et al., 2008). Of course, actions and outcomes decades into the future are uncertain and unknowable, and even the best model cannot precisely predict economic or ecological outcomes in 2050 or 2100. Nordhaus himself points out that IAMs (Integrated Assessment Models) cannot be used to predict actual outcomes, but only to estimate the effects of various scenarios or policy choices. "The purpose of integrated assessment models is not to provide definitive answers to these questions [of the trajectories of emissions, growth, or carbon taxes], for no definitive answers are possible, given the inherent uncertainties about many of the relationships. Rather, these models strive to make sure that the answers at least are internally consistent and at best provide a state-of-the-art description of the impacts of different forces and policies (Nordhaus, 2008, p. 9)."

Many studies model reference scenarios and alternative stabilization scenarios, which estimate the effects of targeting certain atmospheric concentrations of CO_2. For instance, the U.S. Climate Change Science Program and the Subcommittee on Global Change Research engaged three leading climate models (IAMs) to explore a reference scenario and four alternative stabilization scenarios based on varying levels of radiative forcing (warming) and corresponding atmospheric concentrations of greenhouse gases by

2100. The models used are the Integrated Global Systems Model (IGSM) by MIT, the MERGE model developed jointly by Stanford University and the Electric Power Research Institute, and the MiniCAM Model of the Joint Global Change Research Institute, a partnership between the Pacific Northwest National Laboratory and the University of Maryland.

In the reference scenarios, radiative forcing in 2100 is three to four times as high as pre-industrial levels, and primary energy consumption increases three to four times 2000 levels as economic growth outpaces improvements in energy efficiency. Global CO_2 emissions in the reference scenario double and nearly triple between 2000 and 2100, reaching 700 to 900 ppm, up from 365 ppm in 1998. Thus the reference scenario results for carbon emissions are well above the levels recommended by Stern, IPCC, and others.

In the various stabilization scenarios of the CCSP report, which correspond roughly to 450, 550, 650, and 750 ppm, CO_2 emissions peak and decline in the 21st century, with the timing dependent upon the level of stringency. The 450 ppm concentration necessitates an immediate decline in CO_2 emissions. In all scenarios, the greenhouse gas reductions require a transformation of the global energy system, including reductions in the demand for energy and changes in the mix of technologies and fuels.

Whether we follow the drastic measures advocated by Stern and others, the gradual policy ramp suggested by Nordhaus, or a pathway in between, virtually all studies of climate change show that emissions reductions in the next century are necessary. This can be done mainly by reducing our use of carbon-based fuel sources, which we can achieve by reducing our levels of energy demand (through efficiency and conservation) and by replacing our carbon-based energy use with low-carbon or carbon-free sources. As mentioned above, some studies also advocate the use of carbon capture and storage (CCS) as a way to reduce our carbon emissions. While this may be a viable solution in the medium term, CCS is not yet a commercially available technology. In this dissertation I will restrict my attention to energy efficiency and renewable energy – mitigation solutions that are already available and in practice.

The transition to a clean-energy economy will entail both costs and benefits. Much of the climate change literature focuses on the costs of adaptation and mitigation, rather than the benefits of doing so (or, in other words, the benefits are only the avoided costs). Even in those studies which find that the overall effect is negative, that the costs outweigh the benefits, the results nevertheless show that the economy will continue to grow, even with so-called 'expensive' climate change policy. The only negative effect is slightly slower growth. For instance, Ross et al. (2009) use the ADAGE IAM to model a reference scenario (continued rise in emissions) and three alternative stabilization scenarios, which correspond to flat-line 2008 emissions, a 50% reduction from 1990 emissions, and an 80% reduction from 1990 emissions (which in turn corresponds to a CO_2 concentration of 384 ppm). In the reference scenario, GDP in 2050 is projected to increase to 149% above 2010 levels. In the three alternative scenarios, it is expected to increase to 147%, 141%, and 131% above 2010 levels by 2050. In all of the modeled scenarios, therefore, GDP increases significantly over 2010 levels. Pollin et al. (2009) also show that many prominent climate change models lead only to a slightly slower growth rate in GDP by 2050, and not an actual decline in GDP. For example, the

ADAGE and IGEM models used by the Environmental Protection Agency to forecast the effects on GDP of a cap-and trade program show only a 0.05 percentage point reduction in the growth rate from 2015 to 2050, reducing GDP growth from 2.35% or 2.41% to instead 2.30% or 2.36% (Pollin, Heintz, & Garrett-Peltier, 2009, p. 41). The IPCC finds that the macroeconomic costs of mitigation rise with the stringency of the stabilization target, and that the costs of stabilization between 710 and 445ppm CO_2-equivalent are between a 1% gain and a 5.5% decrease of global GDP. A 5.5% decrease corresponds to slowing average annual global GDP growth by less than 0.12 percentage points (IPCC, 2007, p. 69). To give an example of the effect that this slower growth would have on income, if we take an annual income level of $50,000 in 2010, and grow it by 2.4% per year[5], that income would reach $129,112 by 2050. If, however, growth slowed by 0.12 percentage points, so that income grew by 2.28% per year instead, we would reach $123,197 by 2050. We would still see a significant rise in income over the period, though the level would be slightly lower with the slower growth rate. In the first case (baseline, no policy change), income is approximately 2.6 times today's level. In the 'slow growth' case (with aggressive policy action), income is 2.5 times today's level by 2050. Thus even 'expensive' climate action results in a significant rise in income. On the other hand, global losses (resulting from inaction or too little action) could be 1 to 5 percent of GDP for a mid-range level of warming, with regional losses substantially higher (IPCC, 2007, p. 69).

[5] 2.4% growth is the baseline growth rate of GDP as projected by the EIA in the 2010 *Annual Energy Outlook*

The clear result of these climate change forecasts and IAM predictions is that climate change mitigation is both necessary and affordable. At worst, the economic impacts of climate mitigation result in slower growth – not negative growth. And through targeted policies, “green growth” may be achievable, and our economy may grow more sustainably as we transition to a more efficient and low-carbon energy system. In subsequent chapters we will see some of these additional benefits not captured by these macro-models of the economy - notably that employment will increase as we invest in more REEE. While the models presented above forecast the effects on GDP, they do not estimate the impacts on employment. CGE models can forecast increases in employment levels that result from increased labor force participation, but they are not well-equipped to forecast changes in the unemployment rate (since most assume full-employment or make other market-clearing assumptions regarding employment). Further, sectoral shifts will be important as our economy converts from the current system of energy production and consumption to a new, low-carbon system. There will be sectoral employment gains and losses that are not easily captured by CGE models (or at the least are not explicitly discussed by these modelers). Sectoral changes are important for understanding training and education needs as well as designing transition assistance and other programs. Therefore it is useful to move beyond CGE models and IAMs to other types of models which have greater sectoral detail and which allow us to explicitly study questions of employment.

We will see below that both energy efficiency and renewable energy must be expanded from today’s levels in order to reduce carbon emissions and mitigate climate change. In this dissertation, I will examine the economic impact of the expansion of energy efficiency and renewable energy. Specifically, I will present a methodology and new data for estimating the employment impacts of REEE investments. While many of the studies in this section advance various strategies that we need to pursue in order to increase our carbon productivity, these studies do not examine the employment impacts of such strategies. From the perspective of environmental sustainability, we may want to follow climate mitigation strategies regardless of their costs. However, political decision makers and the public more generally are also concerned with economic welfare, and any assessment of climate policy must also entail an analysis of the economic effects. I this dissertation I will focus on the economic effects, specifically the employment effects, of economy-wide investments in energy efficiency and renewable energy. We will see below that there is enormous potential for abatement through these types of investments, but that under business-as-usual scenarios, REEE will grow only modestly. If we find that investments in REEE can not only serve our environmental needs but can also expand employment opportunities, there will be greater political support for a clean energy agenda.

Current and Projected Energy Use

In the U.S. in 2008, according to the Energy Information Administration (EIA), we consumed 7.3 quadrillion BTUs (quads) of renewable energy from all sources, mainly biomass and conventional hydroelectric power, with smaller amounts of solar, wind, and geothermal power. In comparison, as shown in table 1, we consumed over 11 times that amount in fossil fuels. Of those 83.4 quads of fossil fuels, close to half were from oil, about one quarter natural gas, and one quarter coal. Of our total energy consumption of 99.305 quads in 2008, therefore, renewable energy made up 7.35% while fossil fuels accounted for 84% (the remainder is nuclear power and imported electricity)[6].

The EIA, in its preview of the 2010 Annual Energy Outlook, estimates that in the reference case scenario (using current policies and conservative growth assumptions), power generation (in billion kilowatt hours) from renewable sources will grow on average 2.7 percent per year from 2007 to 2035.[7] As shown in table 2, the fastest growth occurs in solar photovoltaics, co-firing, and wood and other biomass. In terms of the level of power production from renewable energy, hydropower continues to play the most significant role, followed by wind generation and wood and other biomass. Together, these three sources make up almost 92 percent of renewable power generation.

Even with this significant growth, renewable energy would only make up 10.6% of total energy consumption by 2035 under the EIA's reference case scenario, which continues to be dominated by fossil fuels. This is certainly well below the levels of capacity that scientists and economists have projected are possible for renewable energy production. Further, the reference case scenario of the EIA assumes overall energy consumption rises between 2008 and 2035, implying that gains in efficiency are not great enough to counteract the growth in energy demands. In other words, energy intensity

[6] http://www.eia.doe.gov/cneaf/alternate/page/renew_energy_consump/table1.html, accessed 2/9/10

[7] This does not account for off-grid applications of solar pv installations. While the capacity of this power source is currently close to zero, off-grid solar pv is predicted by the EIA to grow by 19% annually by 2035 in the residential sector, and 6.4% in the commercial sector. By 2035, off-grid solar capacity is expected to have a capacity six times as large as on-grid solar pv.

(the ratio of energy to GDP) is expected to continue decreasing at a rate of 1.9% per year. However, growth in GDP outpaces improvements in energy intensity, as GDP grows on average 2.4% per year. Thus, even though energy efficiency improves, faster income growth causes the overall level of energy demand to rise.

Measuring energy efficiency is not nearly as straightforward as measuring use or market share of renewable energy. One of the difficulties with measuring efficiency is that it can come in two forms: either reduced use of energy for a given service, or greater service for the same amount of energy. The EIA has not yet identified a measure of energy efficiency but instead uses energy intensity as a proxy. Energy intensity is a ratio between energy consumption and gross domestic product or between energy consumption and population.

Over the past 15 years, energy intensity in the U.S. has declined on average by 2.0 percent per year, and the EIA projects that this trend will continue, with energy intensity declining by 1.9% per year from 2008 to 2035 (U.S. Energy Information Administration, 2010). However, GDP is expected to average 2.5% per year over the same period, leading to an overall rise in energy demand. Energy intensity would have to fall more rapidly (energy efficiency would therefore need to rise significantly) to offset the projected rise in energy demand. The conservative efficiency assumptions in the EIA's *Outlook* therefore show a rise in overall energy demand. Other studies, however, show that even with increased growth in population and GDP, energy demand could actually fall by 2030 or 2050 through increased efficiency. Many researchers claim 25-30% energy savings economy-wide are possible (see for example (Ehrhardt-Martinez & Laitner, 2008) and (McKinsey Global Institute, 2007)). A comprehensive study on energy efficiency conducted by the National Academy of Sciences found that "Energy-efficient technologies for residences and commercial buildings, transportation, and industry exist today, or are expected to be developed in the normal course of business, that could save 30 percent of the energy used in the U.S. economy while also saving money (National Academy of Sciences, 2010 (pre-publication copy))."

Efficiency (or lower energy intensity) can be achieved in many ways: through better energy use in the built environment (retrofitting existing residential and non-residential buildings as well as more energy-efficient design of new buildings); through appliance standards and use of more energy-efficient appliances; through changes in energy-intensive industrial processes; and through increased use of mass transit and changes in vehicle technologies.

Finally, while energy use per capita may be declining slightly, the U.S. still lags far behind other industrialized countries such as Germany and France when we look at carbon emissions per capita. This measure captures not only average energy use per person, but specifically consumption of fossil-derived energy per person. In 2008, per capita CO_2 emissions in the U.S. were 19 metric tons, while in France they averaged 6.5 and Germany averaged 10.1. The U.S. also emits more carbon emissions per capita than rapidly industrializing countries such as China and Japan. China's per capita emissions were only 4.9 metric tons in 2008 and India's were 1.3[8]. The differences between the per capita emissions levels of these five countries stem from a combination of the mix of energy sources used in each country as well as the per capita energy use. Most of the differences result from the latter source. For example, if we focus on the electricity

[8] U.S. EIA, International Energy Statistics

sector, the U.S. uses far more electricity per person than any of these other countries. The U.S. averages 13,616 kilowatt hours (kWh) per capita while France averages 7,573 kWh/capita, Germany averages 7,185 kWh/capita, China 2,328, and India 543 kWh/capita[9]. In all cases but France, the level of electricity consumption correlates closely with the level of per capita carbon emissions. And in all countries but France, coal – the most carbon intensive energy source - is the main source of electricity. In France, 77% of electricity comes from nuclear power, thus even though their per capita electricity use is similar to Germany's, their carbon emissions are much lower.

On a per capita basis, therefore, the U.S. uses much more energy than other countries and produces more carbon emissions. The U.S. economy in 2008 was responsible for 19 percent of global carbon emissions, even though the U.S. made up only 4.5 percent of the global population[10]. These measures highlight the need for the U.S. to reduce per capita energy consumption generally and consumption from fossil fuels more specifically. Through implementation of energy efficient technologies and energy efficient buildings, the U.S. can begin to reduce its energy use. And through a switch to low-carbon and carbon-neutral energy sources such as wind and solar energy, the U.S. economy can reduce its carbon emissions while sustaining economic activity.

Carbon Productivity

The concept of "carbon productivity" incorporates many of the issues raised above. It incorporates both energy intensity and carbon emissions, since in essence it is the inverse of the intensity of carbon use. In "The Carbon Productivity Challenge,"

[9] International Energy Agency, Country Statistics, 2007

[10] U.S. Census Bureau

McKinsey authors use the framework of carbon productivity to analyze the carbon emissions abatement levels that will be necessary to meet the recommendations of IPCC, Stern, and others (McKinsey Global Institute, 2008). "Carbon productivity" is the amount of GDP produced per unit of carbon equivalent emissions (CO_2e). To attain the dual objectives of economic growth and reduced carbon emissions, we need to drastically increase our carbon productivity. The authors estimate that to meet "common discussed abatement paths [such as those outlined by Stern and IPCC]" we need a ten-fold increase in carbon productivity, from $740 GDP per ton of CO_2e today to $7,300 GDP per ton CO_2e by 2050" (McKinsey Global Institute, 2008, p. 7).

The Stern Review, discussed earlier, proposes a 2050 target of 20 gigatons of CO_2e to achieve 500 parts per million (ppm) concentration with no overshoot.[11,12] To meet this goal of emitting no more than 20 $GtCO_2e$ by 2050, along with achieving continued economic growth of 3.1 percent per year (globally), McKinsey estimates that global carbon productivity must increase ten-fold over the period.

McKinsey estimates that of the total abatement potential, 24% will come from energy efficiency and 23% from growth in the use of renewable energy (the remainder is attributable to behavioral change such as using more public transportation or lowering thermostats, technological development which accelerates the conversion to renewable energy, and increasing carbon sinks[13]). Energy efficiency investments will occur mainly

[11] "Overshoot" means that this target can be temporarily exceeded before it is finally achieved.

[12] Note here that gigatons of CO2e are an annual emissions rate, while 500 ppm is an atmospheric concentration of CO2.

[13] "Carbon sinks" refer to parts of the eco-system which naturally absorb carbon. They can be expanded through avoided deforestation along with afforestation and reforestation.

in the industrial and residential sectors, followed by transformation (reducing energy losses as we transform one energy source into another), then transportation and finally commercial energy use. According to McKinsey, by 2020 we could save about 18 quads (over 13 percent of global energy savings) in the U.S. through efficiency investments. These energy savings will continue to grow through 2030 and 2050. Many studies, such as the CCSP report, find that emissions reductions in the electricity sector come at a lower price than in other sectors, and therefore efficiency improvement and decarbonization will happen the most significantly in the electricity sector (Clarke, et al., 2007).

Mitigation options presented by the IPCC include behavioral changes, carbon pricing, and instituting a wide array of mitigation technologies, including but not limited to: renewable heat and power; nuclear power; carbon dioxide capture and storage; more fuel-efficient vehicles; hybrid vehicles; shifts in transport to rail and public transportation or non-motorized options; efficient lighting and appliances; heat and power recovery in industry; improved land management and cultivation techniques in agriculture; afforestation; reforestation; composting organic waste; and landfill methane recovery (IPCC, 2007, p. 60).

In their comparison of models that estimate the carbon dioxide mitigation potential of various technologies, the IPCC finds that energy efficiency and conservation offer the highest level of mitigation potential, followed by renewable energy, followed by nuclear power and fossil-fuel switching, and finally carbon capture and sequestration (IPCC, 2007, p. 68).

Energy-efficiency is the low-hanging fruit. As shown in abatement cost curves,[14] many energy efficiency investments have so-called "negative costs". That is, the discounted flow of benefits resulting from the EE investments is greater than the initial costs of those investments. "Negative costs," in the EE literature, is another term for positive value – namely the financial benefits resulting from savings on energy costs. McKinsey estimates that approximately 7 gigatons of annual emissions would be at negative cost to society, which is about one quarter of the abatement potential (McKinsey Global Institute, 2008).

Another prominent strategy, decarbonizing energy sources, is comprised of expanding renewable energy production, increasing use of carbon capture and sequestration (CCS) technology (which McKinsey authors assume will not be commercially viable before 2020), and reducing demand for oil and gas through more fuel efficient vehicles and other technologies. Under McKinsey recommendations, with currently available technologies, renewables themselves would grow from today's level of 8% of supply to 23% by 2030. Because CCS is not expected to be commercially viable before 2020, the decarbonization of energy sources can only happen through a switch to renewable sources such as wind, water, and solar, and through reduced use of fossil fuels. After 2020, CCS may also contribute to this strategy.

In this introduction, we have seen that carbon emissions have reached unsustainable levels and that they must be reduced in order to maintain the health of our

[14] The abatement cost curve shows the abatement potential (in levels of carbon emissions reductions) plotted against the cost of each abatement strategy. The McKinsey ACC ranges from "negative costs" for energy efficiency initiatives that have a very short payback period to high-cost strategies such as industrial carbon capture and sequestration.

planet and to avoid or reduce the economic damages that could result from climate change. We have also seen that there is great potential for both energy efficiency and renewable energy to reduce our carbon emissions through technologies that are currently available. The question at hand is whether a shift to a more efficient and renewable energy system can also contribute to the growth of employment. In the next chapter, we review studies which address the employment impacts of a clean energy transition.

CHAPTER 2

LITERATURE REVIEW

Introduction

The majority of Americans (85%) believe that climate change is occurring, but only slightly more than half of those believe it is attributable to human causes such as the burning of fossil fuels. Among scientists, however, 84 percent find that climate change is due to human activity, and 70 percent view it as a serious problem.[15] Thus, there is agreement approaching consensus in the scientific community, and significant recognition in the general public, that climate change is present and problematic. However, for the first time in 25 years, in March 2009 Americans responded to a Gallup poll that focusing on economic growth is more important than tackling environmental issues.[16] An increasing number of economic researchers are focusing on the economic impacts of climate change action, partly because any policy for reducing carbon emissions will only have broad support if it also can improve economic well-being, according to standard measures such as GDP per capita. Some of the analysis of global climate change focuses on the costs of mitigation versus inaction, namely in terms of GDP growth. Here we generally see Computable General Equilibrium (CGE) models which forecast GDP (nationally or globally) over a long time horizon, such as the IAM models discussed in the introduction. Other analyses focus on near-term and more

[15] Pew Research Center, July 2009, http://people-press.org/report/?pageid=1550

[16] http://www.gallup.com/poll/116962/americans-economy-takes-precedence-environment.aspx

regionally-specific economic impacts. These studies primarily use Input-Output (I-O) models, case studies, or some combination of primary data used with an I-O framework. Below I outline the various models used to estimate the economic impacts of climate change, with particular attention to those used to analyze employment.

<u>Estimating the Employment Impacts of Energy Policy</u>

Overview of models

In a 2002 article, Peter Berck and Sandra Hoffman outline and describe various modeling methods that can be used by economists and others to study the employment impacts of environmental and natural resource policies (Berck & Hoffman, 2002).[17] Berck and Hoffman outline five basic approaches to evaluating the effect of a policy action on employment:

1. Supply and demand analysis of the affected sector;
2. partial equilibrium analysis of multiple markets;
3. fixed-price, general equilibrium simulations (input-output (I-O) and social accounting matrix (SAM) multiplier models);
4. non-linear, general equilibrium simulations (Computable General Equilibrium (CGE) models); and
5. econometric estimation of the adjustment process, particularly time series analysis.

[17] These authors note the importance of analyzing impacts on the level of employment, rather than the unemployment rate per se, because of the implications and usefulness for politicians, who tend to have more impact on job creation than on the employment rate (which depends upon labor force participation).

Berck and Hoffman go on to describe the merits and drawbacks of each, and further describe how each method operates. They note that the first two approaches (single- and multi-market analysis) do not capture economy-wide impacts. I-O, SAM, and CGE models represent a continuum of closely related models. They write:

> I-O and SAM models provide an upper bound on employment impacts because their Leontief production functions do not allow for adjustment through factor substitution. For the same reason, they can be thought of as simulating very short-run adjustment. CGE models allow for factor substitution in response to changes in relative price. At an extreme, a perfectly neoclassical CGE model will have no aggregate change in employment, and therefore represents a lower bound on possible aggregate employment effects...More commonly, CGE models include migration or labor force participation equations that allow aggregate employment to change in response to changes in compensation.

In their assessment of linear models, Berck and Hoffman note that I-O and SAM models are by far the most widely used models to assess employment impacts. SAM expands upon the basic I-O model by including more detailed final demand sectors (such as households at different income levels and governments at different levels).

In comparison to linear models, which are useful and most appropriate for short-run analysis, CGE models build upon the I-O base by incorporating econometric equations which model non-linearities such as factor substitution and technological change. CGE models can therefore model the adjustment process and may be more suitable to long-run forecasting (though not necessarily for employment, as we will see below). However they are computationally expensive, generally including hundreds of equations and significantly more data. Each relationship in the economy must be modeled, and therefore is subject to data availability as well as the modeler's judgment.

While CGE models may be more suitable to long-run forecasting than the simpler, more transparent I-O models which are at their core, CGE models must make a number of assumptions in order for the model to 'close' – in order to reach a unique, optimal, equilibrium solution. Neoclassical CGE models assume market-clearing through changes in relative prices, assume that individuals are self-interested and act to maximize utility, and that firms are perfectly competitive and therefore there is no real profit in the system. In a CGE model, therefore, there is no involuntary unemployment, as firms decide whether or not to hire workers based on the wages and the factor prices of capital, energy, or other inputs, and individuals choose whether or not to work and how much to work based on the wage they would earn in the labor market.[18] Employment is generally considered 'full' in CGE models since any change in employment *levels* does not affect the unemployment *rate* – changes in wages affect the labor force participation rate, not the unemployment rate.

Because the CGE model has an input-output foundation, both CGE models and I-O models are capable of analyzing inter-industry linkages and determining output effects resulting from changes in intermediate and final demands. However, the I-O model is

---

[18] Heterodox CGE models, including structuralist models such as those developed and reviewed by Lance Taylor (1990), incorporate analysis of institutions and political economy, unlike neoclassical CGE models which generally rely on optimizing agents and full employment. In a structuralist CGE model, distribution (e.g. between wages and profits) matters, and employment and wages could both rise as workers gain more power. In a neoclassical CGE model, however, distribution and class power are not included in the analysis, and higher wages generally imply lower employment, as relative prices and factor substitution lead firms to substitute capital for higher-wage labor. The assumptions underlying these categories of CGE models can therefore lead to very different outcomes, and to my knowledge most if not all CGE models used to study climate change are built upon neoclassical foundations.

much simpler and more transparent, and because it does not require market-clearing conditions, it is more suitable to studying questions of short-run employment changes. Notably, I-O models do not assume full employment, and therefore a shift in demand (for the outputs of one or more industry) may result in higher employment, even without a change in wages. In the neoclassical CGE framework, more workers enter the labor force in response to higher wages. But in the I-O framework, which does not make assumptions about relative prices or assume full employment, some individuals may enter the workforce out of involuntary unemployment, even without a change in wage inducing them into employment.

While CGE models are dynamic and can be useful forecasting tools, mainstream CGE models (such as those most often used to study climate change impacts) are therefore not particularly well adapted to studying questions of employment impacts. In the short run, in an economy with slack resources (such as unemployed individuals), Input-Output models are better suited to studying employment impacts than are CGE models. Because of the limitations of CGE models for studying these transitional employment effects, I will not explicitly discuss any of these models here.

Above I situated various models within the framework of climate change policy and action. In this dissertation, however, I focus my attention on investments in renewable energy and energy efficiency (REEE), which will play an important role in reducing carbon emissions. There is a small but rapidly growing body of literature on the employment impacts of expanding the renewable energy and energy efficiency industry. Much of the work undertaken in this area is done so either to combat the notion that there is a trade-off in environmental and economic goals, or to present a clean energy path toward meeting energy demands. Put another way, the question at hand is whether we can further the agenda of environmental sustainability while also sustaining economic growth. And if we can indeed meet our environmental and economic goals through a program of expanded REEE, will expansion of this industry create decent employment opportunities?

Within the existing body of literature that addresses these questions, I find that the majority of studies are themselves literature reviews or presentations of summary statistics with prose analysis. Only a handful of studies use empirical modeling to test the hypothesis that an expanded REEE industry will generate growth in employment. We will see that these latter studies make an important contribution towards developing a methodology for quantifying the employment impacts of REEE, but that they are constrained in their effectiveness because of limitations in the data. Below I focus on the models that analyze employment impacts of REEE investments, as well as non-modeled approaches such as case studies.

Input-Output and Linear Models

The most widely-used method to estimate the employment impacts of REEE investments are input-output models or other linear models built on an I-O or SAM platform, as mentioned above (Berck & Hoffman, 2002). Within the category of I-O and linear models, we find two broad approaches.

The first approach estimates the employment resulting as a direct consequence of investments in REEE technologies. Namely, the manufacture and installation of REEE technologies will create employment in those industries that produce, install, and service the technologies, as well as in industries with forward or backward linkages to the REEE industries. This approach uses the I-O framework to simulate increased demand for REEE goods and services and then estimates the economy-wide employment effects that result.

The second approach uses the I-O framework but instead of estimating employment resulting directly from REEE investments, this approach estimates the energy savings that will accrue to users (households and businesses) and then uses an I-O model to estimate the employment impacts of channeling those savings into other sectors. Essentially, this approach models the employment impacts of changing industrial spending patterns.

The I-O framework is useful for estimating "economy-wide" employment impacts because it captures not only the employment created directly in the company producing a good or providing a service, but the I-O model also captures employment in companies throughout the supply chain. There are three categories of employment creation that result from increased demand for the goods and services of any given industry. The first is the direct effect - the personnel employed by the industry in question, such as the wind turbine industry. The second level of employment creation is the indirect effect, which is the employment in the industries that supply goods and services to the industry in question, such as gearboxes and fabricated metal in the case of wind. Finally, we have the induced effect - as employees in the wind and fabricated metal industries spend their earnings, they generate demand for goods and services which in turn creates 'induced' employment. This induced effect is simply a way of specifying a consumption multiplier generated by an increase in expenditures targeted at a specific sector, rather than an economy-wide expenditure increase. To estimate the overall employment impacts resulting from expansion of an industry, therefore, it is necessary to measure the direct, indirect, and induced effects. The I-O model allows us to do just this, and thus to estimate the economy-wide employment impacts of increased demand for renewable energy and energy efficiency.

The majority of the studies presented below estimate only the direct and indirect employment impacts of the REEE industry. Pollin et al. (2008, 2009), Scott et al. (2008), Roland-Holst (2008), and The Perryman Group (2003) estimate these plus the induced effects. All of these authors measure employment impacts by use of models built upon an input-output framework. The detailed methodology of the input-output framework will be presented in the next chapter. Here we will simply note that an I-O model allows the user to estimate changes in output or employment through simulated changes in final demand. If final demand for REEE output increases (say, households want to buy more solar panels or businesses want to weatherize their facilities), then output and employment will increase in the REEE industry itself as well as in other industries which supply goods and services to the REEE industry. Researchers use the I-O model to study both sectoral changes and economy-wide changes in employment.

The current I-O tables, however, do not recognize REEE businesses as constituting an industry. Rather, these businesses have been classified as part of other industries in the I-O tables. For example, we might find solar pv manufacturing businesses as part of the electrical goods manufacturing sector, and building weatherization as part of the construction industry. Despite the current data limitations, some researchers have developed methods to analyze the economy-wide effects of investment in the REEE industry in comparison to investments in other industries such as oil refining or coal mining. Here we present this research, and later we expand the methods previously used to study the REEE industry. While it is possible to estimate direct employment in the REEE industry through extensive surveys, only the I-O model allows us to study the indirect and induced effects, and thus to estimate the full economy-wide impact. The studies reviewed below represent various attempts to estimate REEE employment and to overcome limitations inherent in the I-O tables with current industrial classifications.

Employment Created Directly through REEE Investment

In recent years, a number of authors have attempted to estimate economy-wide employment resulting from REEE investments. While many studies focus on one specific technology or industry, a few take a broader scope and analyze a combination of renewable energy and energy efficiency investments.

We start with a study of the wind industry, conducted by the European Wind Energy Association (2004). This multi-volume study analyzes all facets of the wind industry in Europe. Here I concentrate on Volume 3, which focuses on employment and market demand in the wind industry. The authors use I-O analysis and provide a detailed description of the methodology used in assessing the direct and indirect employment impacts of the manufacture, installation and operation of wind turbines. The authors use input-output tables from Denmark, Germany, and Spain, the three countries which provide 90% of Europe's employment in the wind energy sector. As I mentioned above, the European input-output tables (like the U.S. I-O tables) do not themselves include wind energy or renewable energy as an industry. The authors therefore must supplement the existing I-O tables, and do so with data gathered by surveying wind energy associations in these countries. They do not directly expand the I-O tables. Rather, they use information on the inputs to wind energy manufacturing, installation and operation to estimate the direct employment effects, and then estimate the indirect requirements by using employment multipliers from relevant intermediate goods-producing industries.

This study moves us closer to overcoming the data limitations inherent in the I-O tables. The EWEA study collects data directly from wind energy firms and associations. The authors can therefore assess more readily the direct as well as indirect employment requirements of the wind energy. Of course, this study is restricted to wind and does not include other renewable energy technologies or energy efficiency. However, the study provides insight in how to proceed in gathering the appropriate data relevant to our question.

Through interviews and survey data collected in 2003, the EWEA authors are able to estimate that throughout Europe in 2002, approximately 31,000 people were employed in wind turbine manufacturing, 14,650 in turbine installation, and 2,800 in maintenance. In order to assess the indirect employment impacts, the authors rely on this same survey data, plus assessments made by the national wind associations of Denmark and Germany, as well as data from Eurostat's input-output tables. By using survey data, the authors determine the components involved in turbine manufacture. They then categorize these components into industries which exist in the I-O tables and use the industry-appropriate employment multiplier to arrive at a weighted average figure for indirect employment in wind turbine manufacturing. They conduct similar exercises for installation and maintenance.

The EWEA employment multipliers range from 8.2 jobs per €1 million in office and data processing machines to 15.1 jobs per €1 million in metal processing. Like other studies we review below, the EWEA study integrates a labor productivity estimate, which they assume is the same across industries (unlike studies such as Hillebrand et al. (2006) which assign industry-specific labor productivities). The authors conclude that direct plus indirect employment in the wind industry in Europe in 2002 was approximately 72,000 people. Thus, the Type I multiplier would be about 1.5, which means that for every job directly created in the wind industry, another ½ of a job is created in the supplying industries. The authors estimate that wind creates 11.21 jobs per €1 million (in 2002) and that with productivity increases of 2 percent per year, by 2020 the wind industry multiplier would fall to 7.79. This study restricts estimates to direct and indirect effects and does not include induced effects. Despite this possible shortcoming, the EWEA (2004) study makes an important contribution towards developing a method for assessing the economy-wide employment impacts of an industry that is not recognized in the existing input-output tables.

Another European study (Hillebrand, et al., 2006) evaluates the employment impacts of renewable energy in Germany. In this paper, the authors model the economic effects of increasing the share of renewables in electricity, from 5% to 12% by 2010. They find that there are competing effects - on the one hand, there is an expansionary effect from investment, which is greater in the early years in some industries and in the later years in others, and then they find a longer-term contractionary effect resulting from increased electricity prices.

The authors augment the static I-O model to include dynamic effects such as price changes, substitution, and changes in government revenues and spending. Their integrated model includes a goods model, a price model, a capital stock accounting segment, a labor market model and a redistribution model. Hillebrand et al. note that investment effects will lead to economic and employment growth, and that expansion of renewable energies will involve additional investments in production facilities in addition to transportation and distribution facilities. "The main beneficiaries of these investments are the investment goods industries, especially the sectors concerning electrical and optical equipment, construction, and machinery, all of which will face decreasing investment amounts over time. In contrast, the fabricated metal products industry will - although on a substantially lower level - increasingly benefit from the expansion of renewable energies. This is mainly due to the rising number of new photovoltaic installations (p. 3487)." The employment effect is therefore stronger in earlier years than in later years, due to declining new employment from new production facilities. The government budget will have positive impacts from two sources. First, tax revenue will increase from new businesses and new employment. Second, the positive employment effects will lead to decreased public expenditures for welfare programs or other transfer programs.

In the short-run, therefore, Hillebrand et al. estimate that there will be a net gain in employment economy-wide. In the longer term, however, employment will rise more slowly and may eventually decline. The cost effect of using more renewable energy is what leads to somewhat of a contraction in employment. The authors assume that since renewable energy is more expensive than conventional energy, that electricity prices will necessarily rise. They take no account (or at least make no mention) of the fact that renewable prices might actually fall when these technologies become more diffuse, or that technological innovation might result in lower-cost renewable technologies and therefore lower electricity prices. The contractionary effects that they find, therefore, are likely greater than they would find if they assumed a more modest price increase, or if real electricity prices stayed relatively constant to today's level.

The EWEA and Hillebrand studies focus only on renewable energy technologies, and do not include energy efficiency. Next I review three studies which take a more comprehensive view of REEE investments and attempt to measure economy-wide employment impacts, including direct, indirect, and induced employment.

The first set of studies I review in this group are produced the Political Economy Research Institute (Pollin, Heintz and Garrett-Peltier (2009); Pollin and Garrett-Peltier (2009); Pollin et al. (2008)). In these studies, my co-authors and I use the framework of the EWEA report to model economy-wide investments in REEE. Specifically, we create a ‘synthetic’ REEE industry by assigning industries and weights to various components of REEE technologies. We can then simulate increased demand for REEE goods and services and estimate the resulting employment impacts. I will return to a detailed discussion of this methodology in Chapter 5, since this provides us with a reasonable framework for estimating the employment effects of REEE investments, despite the non-existence of this industry in public I-O tables. Here I will note that the Pollin et al. studies model a ‘green program’ which consists of investments in building weatherization

(40%); mass transit and freight rail (20%); smart grid, wind, solar, and biomass (10% each). Each of these industries in turn is composed of various manufactured goods (fabricated metal, electrical goods, etc.) and services (construction, technical services, and so on). We find that on average, each $1 million of investment in REEE creates 16.7 jobs economy-wide, compared to only 5.3 in fossil fuels (oil, gas, coal), and that a shift to REEE will create a large number of jobs economy-wide. For example, a $150 billion investment shift from fossil fuels to REEE would lead to a net increase of 1.7 million jobs. This includes the creation of 2.5 million jobs in REEE, minus the contraction of 800,000 in fossil fuels, if spending in fossil fuels decreased by the same amount as spending in REEE increased (Pollin, Heintz, & Garrett-Peltier, 2009). The I-O model used by Pollin et al. is a static model, which means it is valid for short-term estimates but does not include dynamic effects such as price changes and factor substitution. As pointed out by Berck and Hoffman (2002), it may thus represent an upper bound of job creation. However, since 70% of the REEE investments in Pollin et. al are targeted to energy efficiency, which lead to energy cost savings which can be channeled to other productive purposes, the overall employment effect may actually rise, indicating that these estimates are not necessarily an upper bound.

In 2009, Roger Bezdek , under commission from the American Solar Energy Society, estimated the employment impacts of various environmental policies using a method similar to that used by Pollin et al. (Bezdek, 2009). This study is an extension of an earlier study led by Bezdek, "Tackling Climate Change in the U.S.", in which the authors assess the potential for reducing carbon emissions in the U.S. through deployment of REEE technologies. In this 2009 report, Bezdek estimates the job impacts of those earlier recommendations. He uses input-output modeling as well as an occupation-by-industry matrix to predict occupational outcomes.

Bezdek finds that from 2007 to 2030, the REEE industry could quadruple, creating a net gain of 4.5 million jobs in clean energy over the period. The increased size of the renewable and efficiency industry is the result of an aggressive policy scenario designed to reduce carbon emissions to 80% below 2005 values by 2050. The net changes in energy spending and jobs account for the losses in conventional energy production coupled with a rise in REEE-related spending and employment. The job estimates themselves are derived through input-output modeling, and are essentially the jobs per dollar of REEE investments minus the jobs per dollar of fossil fuels, times the total cost of the REEE deployment. In order to estimate total costs, the authors consider deployment curves for each technology (how many units of energy output or efficiency are produced or saved annually by each technology), then estimate the deployment cost in each year of deployment. These costs, in turn, account for supply curves, R&D, and learning curves, and the analysts use life-cycle cost analysis to estimate the cost per year for each technology. In estimating job impacts, the authors take into account these factors and adjust production functions so that the number of jobs created in solar, for example, will rise from 2020 to 2030, but in wind the number will fall. The total number REEE jobs will continue to grow from 2020 to 2030, and the largest segment of job creation is in energy efficiency.

Finally, I will mention the work done by the Perryman Group, who estimated employment impacts for the Apollo Alliance, an alliance of businesses and non-governmental organizations that advocates for a transition to a clean energy economy.

The Perryman Group (herein TPG) produced a set of employment estimates using a proprietary model built upon an I-O base (The Perryman Group, 2003).

The TPG report, while not as detailed in the methodology as the EWEA report, is nonetheless useful in that it provides an example for assessing the economy-wide job impacts of a massive expansion of both renewable energy and energy efficiency. The Apollo Plan calls for public investment in a broad package of energy reforms. The Apollo Alliance (at the time this report was written) recommended a "10 Point Plan" which includes the following:

- $30 billion in regulations and incentives to strengthen renewable energy markets, such as guaranteeing production tax credits and creating federal matching funds
- $6 billion to support development of bio-energy, including increased funding for R&D and demonstration programs
- $30 billion in production tax credits and subsidies to increase production of American-made fuel-efficient vehicles
- $42 billion in tax incentives to increase energy efficiency in manufacturing
- $42 billion for green building tax credits
- $34 billion to support the Low Income Home Energy Assistance Program
- $20 billion to develop new transit infrastructure
- Other funding to support hydrogen fuel cell RD&D, to develop the electrical transmission grid, to increase appliance standards, to finance energy-efficient home improvements, to fund brownfield redevelopment, to provide support for regional planning, to develop high-speed rail, to upgrade existing transportation networks, to upgrade municipal water infrastructure. This funding includes a variety of R&D, tax policy and direct expenditures.

The Perryman Group estimates that the effects of the proposed Apollo plan investments of $313 billion over a 10-year period include the addition of $1.35 trillion in Gross Domestic Product and 19.4 million person-years of employment (cumulative). This increased GDP is the result of targeted federal spending which leverages additional private spending. Federal spending of $313 billion over the 10-year period leverages additional private spending, for total cumulative expenditures of close to $3 trillion.[19] Of this, $1.35 trillion is additional GDP while the remainder is intermediate costs. This is the cumulative amount, thus for each year of the program, expenditures equal close to $300 billion (combined public and private), and close to 2 million jobs are supported economy-wide (including direct, indirect, and induced employment).

The methodology used by TPG (2003) is based on an input-output framework. Estimates of direct spending on programs in the Apollo project were provided to the Perryman Group by the Apollo Alliance, and were then used in the I-O table manipulations. TPG has a proprietary model called the US Multi-Regional Impact Assessment System (USMRIAS). They describe it as follows:

> The USMRIAS is somewhat similar in format to the Input-Output Model of the United States and the Regional Input-Output Modeling System, both of which are maintained by the US Department of Commerce. The model developed by TPG, however, incorporates several important enhancements and refinements. Specifically, the expanded system includes (1) comprehensive 500-sector coverage for any county, multicounty, or urban region; (2) calculation of both total expenditures and value-added by industry and region; (3) direct estimation of expenditures for multiple basic input choices (expenditures, output, income, or employment); (4) extensive parameter localization[20]; (5) price adjustments for real and nominal assessments by sectors and areas; (6) measurement of the induced impacts associated with payrolls and consumer spending; (7) embedded modules to estimate multi-sectoral direct spending effects; (8) estimation of retail spending activity by consumers; and (9)

[19] The explanation of the methodology and assumptions used to derive this leveraging ratio as well as the total effects on GDP are not discussed in the Perryman report. The inputs used by Perryman are "corroborative" and their model is proprietary, therefore it is not possible to examine their spending, GDP, and employment levels in any depth.

[20] The term "extensive parameter localization" is not described in the Perryman methodology paper, and is a term with which I am otherwise unfamiliar.

> comprehensive linkage and integration capabilities with a wide variety of econometric, real estate, occupational, and fiscal impact models. The models used for the present investigation have been thoroughly tested for reasonableness and historical reliability (pp. 9-10)[21].

Thus, this study builds upon some of the previous work in this field by using a model that captures direct, indirect and induced effects. TPG uses data from the BEA, the BLS and the ACCRA Cost of Living Index for regional spending patterns (to capture induced effects). However, we should be cautious in analyzing the results. Unfortunately, as mentioned above, we cannot decipher the specific effects on employment that expansion of the REEE industry would generate. Like the studies previously reviewed (with the exception of EWEA (2004)), TPG does not have access to data on the REEE industry that they could incorporate into their input-output analysis. There does not appear to be any direct surveying of renewable energy firms, and it is unclear how the Perryman Group arrives at its job estimates for investment in renewable energy. For other sectors, they may have reasonable proxies, such as energy efficiency through home weatherization being proxied by home re-modeling, or the manufacture of hybrid vehicles being proxied by auto manufacture. Perryman can thus make reasonable estimates of energy efficiency industries, but can only cite other sources when discussing the job impacts of wind and solar technologies. While TPG uses an input-output framework, their model is proprietary and therefore the assumptions and results cannot be verified.

[21] The authors do not explicitly describe the types of tests used to assess “reasonableness and historical reliability”.

The five sets of studies reviewed above use similar methods to estimate employment. The first (EWEA) focuses only on wind, the second (Hillebrand et al.) on renewables more generally, and the last three sets (PERI, Bezdek, TPG) take a more comprehensive approach, modeling direct, indirect, and induced effects of employment created by expanding both renewable energy and energy efficiency. All of these studies use a jobs-per-dollar approach to analyzing investments in REEE. That is, they estimate how many jobs will result from a given level of spending in the clean energy economy, and in some cases, such as Pollin et al. and Bezdek et al., analyze the effects of a dollar-for-dollar shift from fossil fuel spending into clean energy spending.

Employment Created through Energy Savings

The next set of studies also uses an input-output framework, but instead of analyzing jobs that result from clean energy investments, as the above studies do, these studies instead estimate the energy savings that will result from efficiency investments, and then channel those savings into other sectors and analyze the net job impacts of this shift in the distribution of spending. This type of study is typified by John "Skip" Laitner (multiple studies) and Roland-Holst (2008). The premise of these works is that the traditional energy sector is capital-intensive, and that households and businesses that reduce their energy expenses will spend those savings in other sectors which are more labor-intensive. Thus the dollar-for-dollar shift from utilities, transportation fuels, and other energy goods, into other (more labor-intensive) sectors, will create a positive employment effect.

Since energy efficiency is not an industry or sector categorized in the existing I-O tables, Laitner et al (1998) try to overcome this constraint by using the I-O model to estimate employment impacts by hypothesizing how alternative energy efficiency scenarios would change consumption and thus production patterns across industries. The authors estimate the direct and indirect employment created by an increase in final demand. This will necessarily understate the total employment effects of a given change in final demand, since it does not include the employment resulting from the increased earnings and consumption by households (the induced effects).

To estimate the direct and indirect multipliers, Laitner et al. (1998) use the 1993 IMPLAN model (IMpact analysis for PLANning) which was developed by the Minnesota IMPLAN Group. Using this model, the authors can compare the total number of jobs both directly and indirectly created within the United States. They find, for example, that multipliers are lowest in industries such as refining, utilities, oil and gas extraction, and motor vehicles – industries which have low labor-intensity in production. The multipliers are highest in industries such as education, government, agriculture, and financial services – industries with high labor-intensities of production.

There is, as previously mentioned, no REEE industry in the current I-O tables, and therefore no multiplier for the REEE industry. In order to capture the employment impacts of increased energy efficiency, Laitner et al. make some assumptions as to how spending will change among the sectors contained in the I-O tables. They assume, for example, that 90% of efficiency investments would be spent in the United States, they make assumptions about labor productivity (sector-specific), they assume that 80% of the investment upgrades would be financed by bank loans and that 15% of investment in building and industrial sectors would go towards marketing expenditures. The labor productivity estimates were calculated from BLS projections, and the values for financing were taken from an earlier study by Geller et al (1992). There was no discussion of the value chosen for domestic versus international efficiency investments. After making these financing and spending assumptions, the authors then apply them to the existing I-O tables to determine the employment multipliers resulting from these changes in final demand. Having obtained these employment multipliers, they can then determine which industries would be net "winners" or "losers" of jobs. They find, for instance, that jobs will decline in electric utilities, oil and gas extraction, and wholesale trade; while jobs will increase in retail trade, government, construction and financial services. Over their 12-year projection, which is from 1998 to 2010, they predict that the net employment gain economy-wide is 772,859 jobs, that compensation and salaries will increase by $14 billion and that GDP will increase only slightly, by $2.8 billion. Unlike other I-O studies of REEE investments, the results obtained by Laitner et al. are not derived from the investments themselves, but rather from the cost savings that accrue to businesses and households as a result of implementing more energy-efficient technology. As their energy bills decrease, businesses and individuals re-spend these savings in other sectors of the economy which are more labor-intensive than the energy sector, therefore driving up economy-wide employment.

Barrett et al. (2002) conduct a somewhat similar exercise. Like Laitner et al. (1998), they use an existing model to forecast the employment impacts of changes in energy use. Specifically, they outline a policy scenario that calls for:

1. A $50 per ton carbon tax, mostly offset by a payroll tax cut;

2. policies to promote energy efficiency and renewable energy technologies as well as policies to offset competitive impacts on energy-intensive industries ;[22] and

3. transitional assistance to workers and communities (approximately $100,000 per worker).

The authors then use the LIFT (Longterm Interindustry Forecasting Tool) model to forecast employment impacts under this set of policies. The LIFT model was developed in the 1960s by the Inforum modeling group at the University of Maryland, and is a 97-sector macromodel of the U.S., built upon an I-O base. Using the LIFT model and their adjustments, they find that GDP would increase very slightly (at most 0.6% by 2020), and that 660,000 net jobs would be created by 2010 and 1.4 million by 2020 (which is about 1% of the 2002 workforce). The primary factor driving these job gains are reductions in the cost of production (due to energy efficiency gains). Furthermore, after-tax compensation would rise. Their findings are thus roughly comparable to those of Laitner et al (1998), using a similar methodology.

In 2007, Laitner et al. extend the 1998 analysis of jobs created through energy efficiency. The authors develop and use a model they call "DEEPER" (Dynamic Energy Efficiency Policy Evaluation Routine) which they describe as "quasi-dynamic" since it

[22] The policy package used in the Barrett et al (2000) study is based on the scenarios created by the U.S. Department of Energy in their Interlaboratory Working Group (2000) report entitled “Scenarios for a Clean Energy Future.” The moderate scenario comprises policies such as information outreach efforts, enhanced R&D, government procurement programs, voluntary industry agreements, technical assistance, stricter codes and standards, feebates, rebates, and tax credits. The advanced scenario expands upon the moderate scenario by including a carbon permit trading system as well increasing government financial involvement.

adjusts energy costs based on the level of energy quantities produced in a given year, and it adjusts labor impacts given the anticipated productivity gains within the key sectors of the Texas economy (Laitner, Eldridge, & Elliot, 2007). The DEEPER model is an Excel-based tool that consists of the following modules: global data; macroeconomic model, which includes the 15-industry I-O based model from IMPLAN; investment and savings; price dynamics; final demand; and results.

As in the Laitner et al. (1998) study, the authors here estimate direct and indirect employment multipliers, and keep households exogenous in the model. They use a 15-industry breakdown, and show employment impacts resulting from $1 million in final demand (for example, 20.4 jobs in agriculture, 3.8 in oil and gas extraction, 2.4 in electric utilities, 13.5 in construction). Their overall job impacts are estimated by doing the following: They assume a zero 12-year change in investment; over this period, they estimate what the job impact would be if $1 million was transferred from other types of spending into installing energy-efficiency equipment, and $1.5 million was saved on energy bills and spent elsewhere in the economy. Installing energy efficiency improvements would generate 13.5 jobs per $1 million (this is exactly the employment figure from construction) and diverting this money from elsewhere would reduce jobs by 11.9 (it is not clear in the report where this figure comes from). Reducing utility revenues would decrease employment by 2.4 jobs per million (therefore 3.6 jobs for $1.5 million) but the money spent elsewhere would increase jobs by 11.9 per million (again, unclear where this comes from) and thus create 17.9 jobs per $1.5 million. The overall employment effects of these transfers of spending are thus 15.9 jobs created per $2.5 million energy-efficiency investments and spending shifts. Laitner et al. conclude that in the first year, the job impact of their policies prescriptions for the state of Texas would be 5,573, a number which just about doubles every five years and reaches 38,291 by 2023. This represents a gain of only 0.3% in the state's employment base.

By sector, the authors note that the four big winners are construction, manufacturing, services and financial services. This results because these sectors benefit from initial investments in EE and also because these sectors will experience higher demand for goods and services as savings from energy bills are re-spent throughout the economy. Again, the Laitner et al. (2007) study must make assumptions about changes in spending patterns to be able to forecast employment changes due to energy efficiency improvements. Like the aforementioned studies, this report is useful in estimating changes in spending that result in changed employment patterns.

In a very recent study, Laitner evaluates the historical evidence on energy efficiency improvements and uses a 'diagnostic tool' to show the outcomes on GDP and employment of using other models with baseline scenarios, typical modeling scenarios (climate change policies as modeled by the EPA and others), and scenarios using American Council for an Energy-Efficient Economy (ACEEE) assumptions of increased efficiency investments (Laitner, 2009). The ACEEE assumptions lead to greater GDP and employment over the period from 2009 to 2050, and imply a decrease in energy intensity and thus a savings in energy use of about 25-30 percent. These EE investments have a short payback period and lead to savings which are channeled to other sectors. As in earlier work, Laitner uses IMPLAN to model the employment multipliers for energy, manufacturing, services, construction, and government. All of these sectors are more labor-intensive than energy. Thus a shift from spending in energy into any other sector will increase employment.

Reference case scenarios in Laitner (2009) show energy demand and prices rising, and thus total energy spending rising. Laitner demonstrates that typical energy modeling (as done by EPA and others) results in a rise in energy prices, and a rise (though slower) in energy demand, resulting in higher overall energy spending in 2050 versus 2009. The ACEEE case shows a net fall in energy demand, so that even with a slight rise in energy prices, total energy spending is lower in 2050 than it is today. Energy prices rise more slowly in this scenario than in the baseline case because of lower demand for energy. Laitner's 'diagnostic tool' shows that in the reference case the total resource cost is $4.2 trillion and would rise to $4.9 trillion in the typical model. But with ACEEE assumptions it in fact falls to $2.7 trillion. This lower energy cost (-$1.5 trillion) leads to a positive net impact on GDP of $456 billion, rather than a net fall in GDP of $229 billion.

Laitner cites work by the Union of Concerned Scientists (Cleetus, Clemmer & Friedman 2009) which contains a "detailed portfolio of technology and program options that would lower U.S. heat-trapping greenhouse gas emissions 56 percent below 2005 levels in 2030. The result of their analysis indicated an annual $414 billion savings for U.S. households, vehicle owners, businesses, and industries by 2030." The net savings to the economy are on the order of $255 billion per year. Over the 20-year period, the net cumulative savings are on the order of $1.7 trillion.

Having evaluated the assumptions and outcomes from various models used to estimate employment impacts of climate change policy, Laitner (2009) points to the drawbacks of using CGE models to analyze these questions. He notes that CGE models fail to value many co-benefits associated with climate solutions (such as non-energy productivity gains[23], improved energy security, better air quality, improved public health), and that they operate under assumptions of rationality and perfectly competitive markets (and as we noted above they also operate under the condition of full employment). Finally, most CGE models use fossil fuel prices as they are currently structured, which means that they are under-priced since they do not account for environmental externalities.

Over the longer term, the results in Laitner (2009) are similar to those in Pollin, Heintz, and Garrett-Peltier (2009). Both studies analyze the predictions of EPA and other environmental models, which show that even under their own assumptions, by 2050 there is only slightly slower GDP growth – not, in fact, a decline in GDP. In other words, GDP grows in all scenarios, reaching levels far above today's. Climate change policies as typically modeled would only lead to a slight postponement (of a few months) in reaching a certain level of GDP over 40 years (reaching the same level of GDP per capita by July 2051 instead of sometime in 2050). The Laitner (2009) study also shows that ACEEE case (of more substantial efficiency investments) would lead to a slight acceleration in GDP growth (reaching the reference case scenario by Aug 2049). The important illustration in both studies is that in all the modeling cases, the economy

[23] Productivity gains, like the other benefits mentioned here, are referred to as "co-benefits" – in this case, benefits attributable to energy efficiency investments that are not directly energy- or cost-related. Non-energy productivity might increase in this case as energy cost savings are channeled into capital equipment or other investments that enhance productivity.

continues to grow, just slightly faster or slower depending on assumptions used in the model.

Another study that uses an approach similar to Laitner (2009) is by David Roland-Holst (2008). The Roland-Holst study is a policy analysis of past and future energy efficiency policies and other climate change policies in the state of California. The author focuses on the household sector in this state, since household consumption is responsible for 70% of the state's GSP and therefore is a leading driver of state energy use[24]. Roland-Holst uses a modified I-O approach that incorporates the effects of climate change policies and innovation.

While he is particularly interested in modeling the effects of AB 32, California's "Global Warming Solutions Act," Roland-Holst also evaluates historical energy efficiency in CA in comparison to the rest of the U.S. Using national and state I-O tables, he finds that from 1972 through 2006, about 1.5 million jobs were created as the result of $56 billion worth of energy savings that were spent in other sectors. (This yields a multiplier of 26.8 jobs per $1 million.) Net, he finds that for every job lost in the fossil fuel sector, 50 jobs were gained in others. These estimates are much higher than those predicted by Laitner et al. (in multiple studies) as well as those predicted by Pollin et al. or others using the I-O methodology.

---

[24] Since households purchase from the building, commercial, and transportation sectors, this approach captures most energy-related transactions. However it excludes one major user of energy and producer of emissions – the industrial sector, from which households do not buy directly.

Though he used an I-O model to estimate historical energy policy, Roland-Holst models the future employment effects of AB32 using the BEAR model (Berkeley Energy and Resources) created by CERES (the Center for Energy, Resources, and Economic Sustainability) at UC Berkeley. This is a CGE model that incorporates emissions and innovation. Using BEAR, Roland-Holst finds that by 2020, emissions goals under AB 32 can be met, and up to 403,000 new efficiency and climate action jobs will be created. This modeling approach is similar to Laitner et al., in that it analyzes the job gains from shifts in spending from the capital-intensive energy sector into more labor-intensive sectors (such as retail and food service). However it differs in that it uses a CGE model. Given the usual full-employment assumption of CGE models, it is unclear how Roland-Holst is able to predict employment changes. Though not explicitly stated in his paper, if employment rises in a CGE model it is due to an increased labor force participation rate, which may result from more people entering the workforce in response to higher compensation or migration. However, if this is what drives Roland-Holst's results it is not explicitly stated in the report. Nonetheless, Roland-Holst, like all of the studies mentioned so far here, predicts a net gain in employment resulting from implementing energy efficiency policies.

Finally, a study commissioned by the Department of Energy's Office of Energy Efficiency and Renewable Energy uses an I-O based model and performs an analysis similar to that of Laitner (Scott, et al., 2008). The authors were commissioned to evaluate the economic impacts of building technology programs, which include energy efficiency upgrades to residential and commercial buildings. The authors develop an I-O based model from BEA data that is modified to account for changes in energy use as well as changes in capital stock, investment, and productivity more generally. They use a 188-sector model, and find that the FY2005 building technologies program could save 27% of the expected growth of building energy use by 2030, creating 446,000 jobs and increasing wage income by $7.8 billion. The authors also find that over the period there will be significant energy and capital cost savings which can be channeled into consumption (residential savings) or productive investment (commercial savings).

Scott et al. note that there is debate over the macroeconomic impacts of energy efficiency programs, namely because of distributional effects (across industrial sectors). Energy bill savings will have positive effects on most sectors but negative effects on the energy sector, giving an uncertain net effect (ex ante). The authors situate their model within the range of models enumerated by Berck and Hoffman (2002) and after reviewing alternative methods, choose to use the I-O approach because it "lends itself readily to analyses of technologies for residential and commercial buildings."

ImSET (the 188-sector model developed by Scott et al.) tracks the corresponding changes to inter-industry purchases of goods and services (and energy in particular), and recalculates the use matrix and the consequent changes to the input-output structure of the economy in each forecast year. This differs from most I-O models, in which a constant I-O structure is usually applied to a change in investment. Savings in the energy, labor, materials, and services from improved energy productivity are the source of subsequent rounds of investment and economic growth. We can therefore view this study as spanning our two categories above - it estimates job creation both from initial investments in efficiency as well as from energy savings and shifts in spending.

Finally, once they have obtained the new vector of output, Scott et al. apply capital/output ratios and investment/output ratios for each sector to estimate the savings in capital expenditures that would accrue from energy efficiency investments. For example, increased efficiency reduces the demand for power plants, pipelines, etc. and thus reduces capital expenditures in those areas, which can be channeled into other (more productive) investments.

We note that within this category of studies (those that model the effects of shifting spending), all of these authors analyze only energy efficiency investments, and do not model renewable energy concurrently. The methodology assumes that financial savings from energy efficiency result in job creation. This type of analysis may or may not be transferable to studying renewable energy, since in shifting from fossil fuel energy to renewables, overall spending on energy may increase or decrease depending on technological diffusion and changing costs of RE. If RE becomes less expensive than fossil fuels are today, then households and businesses might see cost savings that they can channel elsewhere. However if RE remains more expensive than conventional energy, energy bills may rise, causing a shift in spending to energy from other sectors. Thus it will be important to examine the labor intensity of RE. Knowing this, we can model the employment effects in a shift from fossil fuels to RE. While this is not done by Laitner and others in the category of studies presented here, it is in fact analyzed by Pollin, Heintz, and Garrett-Peltier (2009), and we will pursue this methodology below.

Non-Modeled Employment Analysis

The studies presented above use a variety of modeling approaches to estimate REEE employment. Here, I present some alternate methods which use case studies (primary data) as well as secondary data in order to estimate direct employment, and in some cases indirect employment, in various renewable energy technologies. Generally, these studies use a “jobs-per-energy-unit” rather than a “jobs-per-dollar” approach. That is, rather than estimating the cost of a technology and then using an I-O model to estimate employment created by expenditures, these case studies and other non-modeled approaches estimate how many jobs are needed to produce a given RE technology with a given energy production capacity. For example, how many jobs will be created if a company receives an order to produce a 10 megawatt wind turbine? While these studies do not examine economy-wide employment effects, they are nonetheless useful in assessing employment needs for increased production of RE goods.

Case Studies

The first set of studies which use primary data is typified by Kammen et al. In 2004, Kammen, Kapadia, and Fripp published a review of 13 alternative studies of renewable energy and employment. They analyze the main assumptions and models in these 13 studies, and compare estimates of employment in the manufacturing and operations of renewable technologies, based on jobs per MWa (average megawatt). The authors conclude that over a broad range of scenarios, "the renewable energy sector generates more jobs than the fossil fuel energy sector per unit of energy delivered."

In 2009, Daniel Kammen extends this approach, and together with Engel Ditley of Vestas (a large wind energy firm) produces a policy brief comparing jobs in wind energy to those in fossil fuels (on a jobs-per-MW basis). This brief highlights some of the findings from a paper by Kammen and others (2010, described below), and showcases some examples of jobs and economic activity in the wind industry, namely at current and planned Vesta wind technology manufacturing plants. Kammen and Ditley (2009) also review an in-depth study by the European Wind Energy Association showing that wind creates more jobs per MW than fossil fuels. Finally, they also showcase a recent McKinsey & Co. analysis showing that wind creates more jobs per MW than coal, gas, and nuclear power. This 2009 review of wind energy studies shows that on a job-per-MW basis, renewables (in this case wind) generate more jobs than fossil fuels.

Then in 2010 Kammen and others perform a meta-analysis of about 15 other clean energy and jobs studies, and also offer a methodology for comparing employment estimates that were derived by different methods (Wei, Patadia, & Kammen, 2010). They then offer an open-source analytical tool that can be used to model the employment effects of varying renewable portfolio standards (RPS) and energy efficiency measures from 2009 to 2030.

The methodology follows the usual Kammen et al. strategy of comparing jobs per MW across various technologies. This particular study limits itself to the power sector, with attention to evaluating various levels of a national RPS. The authors also attempt to estimate net job creation, with attention to job losses in coal and natural gas[25]. In order to

[25] The authors model the effect of an RPS, which applies to electricity. Since coal and natural gas are the primary fossil sources of electricity, and oil contributes minimally, the

make other estimates comparable, the authors convert all job estimates into job-years per average MW. First they convert all the CIM jobs (Construction Installation Manufacturing) into job-years over the life of the plant (so for example they divide the total estimate of CIM jobs by 25 if the plant life is that many years). Next they use capacity factors to ensure that they can compare employment per unit of energy between technologies that have different capacities. Having made the estimates comparable, they find that renewable energy and low-carbon technologies create more jobs per MW than fossil fuel technologies, and that solar pv creates the most.

They note that most jobs studies only include direct employment, or might also include indirect, but rarely if ever include all three levels (direct, indirect, induced). In their own analysis, they estimate direct and indirect effects for RE but add induced for EE, which they admit will bias the results in favor of EE. Since they report total results and do not separate induced effects from direct and indirect, readers are not able to directly compare the direct and indirect effects of renewable energy to energy efficiency. In the energy efficiency sector they assume that the majority of jobs are from induced effects (90%) with only 10% of the jobs resulting from the actual manufacturing or installation of EE products.[26] For the RE indirect multiplier, they use an average across all technologies of 0.9 (they obtain this value from 3 other studies). This is of course not

---

authors restrict their attention to job losses related to the electric power sector, namely those in coal and natural gas.

[26] This is similar to the Laitner et al approach, which assumes that most employment gains from energy efficiency will result from a shift in spending from the energy sector into more labor-intensive sector. Here in the Wei, Patadia, and Kammen study, the authors refer to this as ‘induced’ job creation.

industry-specific and most likely there is variation across the technologies that an I-O approach could distinguish but theirs cannot.

Their methodology does not account for leakages (especially manufacturing jobs that are offshore) and does not account for regional differences or local versus national analysis. They note that their model would also benefit from including learning curve effects, since jobs in 2030 will likely be lower than their estimates because of technological innovation. Under one back-of-the-envelope learning scenario, this could lead to a multiplier that is 17% lower in 2020 (Wei, Patadia, & Kammen, 2010).

Case Studies Combined with Secondary Data

Finally, the Renewable Energy and Policy Project (REPP) has developed a non-modeled approach which incorporates primary and secondary data, as well as some of the methodological elements presented above. In earlier studies (Singh & Fehrs, 2001), REPP conducted surveys of RE firms to estimate direct jobs in those firms and compare jobs-per-MW between renewable technology production and fossil fuels. In subsequent studies ((Sterzinger & Svrcek, 2005), (Sterzinger, 2006)) they include an indirect multiplier and also use BEA data to indentify employment within the supply chain of renewable technologies.

Singh and Fehrs (2001) estimate the direct labor requirements of the wind, solar, and biomass industries by conducting written and phone surveys of one or more firms in each industry, in addition to data provided in industry journals. They estimate various types of jobs, including those in parts manufacture, delivery of goods to power plants, construction/installation/project management, operation and maintenance for 10 years, and cultivation and collection of biomass fuel. They also offer an overall cost comparison of coal, wind and solar PV. They estimate that for a given $1 million of expenditure, coal generates 3.96 person-years of employment over 10 years, wind 5.70 and solar PV 5.65. Per megawatt of electricity, solar photovoltaic (pv) supports 35.5 person-years, wind supports 4.8 and biomass co-firing can range from 3.8 to 21.8 person years (with co-firing from mill residues on the low end and co-firing from switchgrass and poplar on the high end).

By conducting surveys of firms in these REEE industries, Singh and Fehrs (2001) are able to determine the occupational mix for the labor requirements of renewable energy technologies. They group jobs into 10 categories, which are the following: professional/technical/management; clerical/sales; service; agriculture/forestry; processing; machine trades; benchwork; structural work; miscellaneous. These categories do not correspond directly to the occupational categorization of the BLS. However, this is nonetheless a useful exercise – both because it highlights the importance of surveying to gather the relevant data and also because having a sense of the occupational mix is important in understanding what types of jobs will result from an expansion of REEE.

In the 2005 study by Sterzinger and Svrcek, the authors use wind-industry data to identify the components and costs of wind turbine manufacturing (similarly to the EWEA 2004 study). They then assign NAICS codes (North American Industrial Classification System) to each component so that they can use publicly available data to estimate current employment levels in each component industry. However this only measures employment in firms which *could* manufacture wind turbine components, rather than those that are currently producing for the wind industry. For example, the authors measure employment in “motors and generators” which could be inputs into wind turbines or could be used by other industries such as automobile production. While this study is useful in identifying the relevant industries for the production of renewable energy technologies, the authors are unable to distinguish which part of each industry is unique to renewable energy and which part services other industries and end uses. This is yet another example of the limitations of currently available data, which make it nearly impossible for researchers to use secondary data (such as BEA or BLS) to study RE employment.

In 2006, Sterzinger goes one step beyond this 2005 research and attempts to estimate jobs resulting from various RE technologies, both directly and indirectly. This more recent report (Sterzinger 2006) is the result of a project to update the "jobs calculator", a spreadsheet tool used to calculate jobs resulting from varying Renewable Portfolio Standards (RPS). The industries included in the RPS and calculator are wind, solar, biomass, and geothermal. The jobs estimates (jobs per MW) were derived in a similar way to PERI’s 'synthetic industry' approach. Sterzinger identifies the components of each technology, matches those to NAICS codes, assigns cost shares to each of those, and calculates total costs per MW for each NAICS category. Then he uses a jobs/MW number (based on surveys and interviews) to get a total number of jobs. Since Sterzinger provides both total job estimates and total costs, we can use these to calculate jobs/$ and compare this to results that researchers obtained using input-output analysis.

Sterzinger’s results show 6.39 jobs/$1million in wind, 4.28 in solar, 4.72 in geothermal, 6.16 in biomass, and an average (from total investment of $160.5 billion and total FTE jobs of 850,603) of 5.30 direct jobs per $1 million from these four technologies. Since Sterzinger uses a direct job-per-MW approach, these estimates do not include indirect or induced effects. However Sterzinger does identify the relevant components and costs of these four technologies, and could therefore use an input-output model to estimate economy-wide employment effects. Here, as in the other REPP reports presented in this sector, the focus is on renewable energy and does not include energy efficiency.

Advantages and Disadvantages of Renewable Energy Case Studies

The studies and methods presented in the section above have the advantage of using actual data from the field, such as the number of workers employed in a given wind turbine manufacturing firm, which may in some cases be more useful or accurate than the more aggregated data in the I-O models. I-O models rely on data which are collected from millions of firms and then aggregated into various industries. Thus in using I-O models we are essentially working with industry averages, which may not always be reflective of the experience of individual firms. However, there are also some disadvantages to working only with case study data. First, for the most part these studies only measure direct job creation, and do not enable us to evaluate the economy-wide impacts of a technology. Similarly, this method does not allow researchers to examine net job impacts, since we cannot estimate either economy-wide job gains from RE investments or economy-wide losses in fossil fuel employment. Finally, these studies generally are conducted for only one technology or a limited range of technologies, and may not be broadly applicable to investments in the full spectrum of renewable energy and energy efficiency. These studies are useful, however, in providing data that other researchers can use to derive economy-wide employment impacts, for example, by integrating the data into an input-output model.

Discussion of Choice of Input-Output Model

In this dissertation, I have chosen to employ the input-output model to study employment impacts of REEE investments. This is due both to the advantages of the I-O model that are discussed above, as well as the drawbacks of using other approaches. The I-O model allows us to estimate economy-wide impacts of investments in a range of REEE technologies, and thus has useful macroeconomic implications. Further, it also allows us to evaluate the effects on specific sectors and industries, which is useful for industrial policy as well as employment, training, and readjustment policies.

In the past decade, as we can see from the studies surveyed above, economists have expanded in various ways the input-output methodology used in employment impact analysis. As we will see below, the I-O methodology has existed for over 70 years now, but has only recently been applied to questions of renewable energy and energy efficiency. The authors discussed above demonstrate how this methodology can be used to examine direct and indirect impacts, and how the basic I-O framework can be extended to include induced effects, price effects, productivity changes, and so on. However, many of the studies had to make significant assumptions about the composition of the REEE industry or changes in economy-wide spending patterns, since the REEE industry does not exist as such in the current I-O tables. The EWEA (2004) tries to overcome this limitation by conducting extensive surveys of relevant firms and associations to estimate direct effects and then using the I-O model to estimate indirect effects. However, this is relevant only to the wind industry, and only in Europe. No survey of this magnitude has been conducted in the United States, and to my knowledge, no survey of REEE businesses throughout the U.S. has yet been conducted. Thus, previous research is limited in the estimates it can make and comparisons it can draw regarding employment in REEE.

While significant research on this topic has been underway and continues to grow, there remain many holes to fill in the literature. This dissertation contributes to the REEE literature in a number of ways. First, it extends the methodology used by the EWEA and Pollin et al. to identify an REEE industry within the current I-O tables. Second, I conduct a nationwide survey of REEE firms in the U.S. to expand the data and our knowledge of the REEE industry, and finally I incorporate that data into the BEA's current I-O tables to estimate the employment impacts of REEE investments and compare those to spending in fossil fuels. Through this data collection and methodological extension, I will contribute to the literature by providing an alternative estimation of REEE employment.

CHAPTER 3

USING THE INPUT-OUTPUT MODEL TO STUDY RENEWABLE ENERGY AND ENERGY EFFICIENCY

The Input-Output Model

Background

Wassily Leontief, known as the father of input-output modeling, developed this framework in the 1930's, based on the "tableaux economiques" by Francois Quesnay in the 1750's. Leontief created input-output modeling and used it for impact analysis as early as 1936. Input-output tables are national accounting systems that show linkages between industries and that allow us to see how changes in final demand can affect industrial output both directly and indirectly ((Leontief, 1986), (Miller & Blair, 1985), (Stone, 1961)).

Input-output tables for the U.S. economy are compiled by the Bureau of Economic Analysis (BEA) of the U.S. Department of Commerce. Every five years, in years ending in '2' or '7', the Census Bureau gathers data (in its "Economic Census") and the BEA uses these data along with information from other Census Bureau programs—including annual surveys that cover selected industries, such as manufacturing and services. The I-O tables also incorporate data collected and tabulated by other Federal agencies—including the U.S. Departments of Agriculture, Education, and Energy—and data from a number of private organizations (Horowitz & Planting, 2006). In their comprehensive manual on the BEA input-output accounts, Horowitz and Planting (2006) write that:

> The Economic Census collects most of the essential data required for the tables—such as receipts, inventories, and payrolls—and the data are collected at the level of the smallest operating unit, the "establishment." In addition, the Census Bureau's collection procedures are designed to ensure that no individual establishment is counted more than once. Thus, by relying on the Economic Census data wherever possible, BEA is able to limit duplications that could occur when the Economic Census is used in conjunction with other sources.

While the Economic Census is wide-spread and covers millions of establishments, it nonetheless relies on sampling of small businesses, and some establishments and industries are not included in the Census. Therefore the BEA supplements these Census data with information from other establishment surveys conducted by other agencies as well as by the Commerce Department itself. This includes data from the agricultural sector collected by the US Department of Agriculture, data on fossil fuels and utilities collected by the Energy Information Administration of the U.S. Department of Energy, data on the financial industry from the Securities and Exchange Commission, on insurance from the A.M. Best Company (an insurance rating company that compiles financial information on insurance companies), and data on education from the Department of Education's *Digest of Education Statistics*. The BEA also uses two of its own sources to supplement these outside data sources. It draws from the NIPA (national income and product accounts) for a variety of domestic transactions, and the ITA (international transaction accounts) for imports and exports.

The Economic Census itself, which makes up the backbone of the I-O accounts, was first established in 1810 and consisted of a few questions on manufacturing. It has grown to include over 500 versions of the questionnaire, and collects data from 3.7 million businesses representing over 5 million business establishments in over 1,000 industrial classifications. In addition, the Census Bureau uses administrative records to compile information on 14 million businesses without paid employees plus 1.5 million small-business employers (Horowitz & Planting, 2006).

The BEA uses the data collected from these various sources to construct benchmark input-output tables for close to 500 industries. Between the quinquennial census years, the BEA updates the benchmark tables to produce annual input-output tables at more aggregated levels. In order to perform these annual updates, the Census Bureau compiles samples of companies and conducts a variety of annual surveys. These include the Annual Survey of Manufactures, the Annual Wholesale Trade Survey, the Annual Retail Trade Survey, and the Service Annual Survey which covers various service industries. In addition, BEA uses data from the Census Bureau's *County Business Patterns*, Business Expenses Survey, construction statistics program, and two programs covering government activities – the Census of Governments and the Annual Survey of Government Finances (Horowitz & Planting, 2006).

The input-output tables compiled from these various establishment surveys provide a "snapshot" of the economy. In any given year, they show the inputs used by each industry, the outputs produced by each industry, and the relationship between industry output and final demand among various users. The I-O tables, both at the benchmark level as well as the annual tables, include a "make" table (the commodities produced by each industry), a "use" table (the use of commodities by intermediate and final users), a "direct requirements" table which is an algebraic manipulation of the make and use tables showing the amount of a commodity required by an industry to produce a dollar of the industry's output, and a "total requirements" table which is also known as the "Leontief Inverse Matrix," described below.

The basic structure and subsequent algebra for the input-output model are presented here. We start with a flow table, F, which is an (*n x n*) matrix showing the dollar value of goods and services which are exchanged between the *n* industries in the model. Adding along a column of the flow table will yield the total inputs (in dollars) used by each industry. Adding along a row will yield the total dollar value of output produced by each industry.

To calculate the proportionate use of goods and services that each industry uses of the other industries (and its own products), we need to calculate the coefficients matrix (A), which is derived by dividing each cell of the inter-industry flow table (F_{ij}) by the total industry output of that particular industry (X_j):

$$a_{ij} = F_{ij}/X_j$$

where F_{ij} stands for an element in the flow table and a_{ij} is the corresponding element in the coefficients matrix (A), with *i* and *j* running from 1 to *n*. The element a_{ij} therefore represents the input (product of industry *i*) into the production of one unit of output of industry *j*.

The coefficients table (A), when post-multiplied by the vector of total output (X), yields the intermediate (industry) demands for goods and services. The basic equation for the input-output model is then

$$X = AX + Y$$

where X is an n x 1 column vector of total output for each of n industries, AX is the output to meet intermediate demand (with the dimensions of A being $n \times n$ and the dimensions of X being $n \times 1$), and Y is an $n \times 1$ vector of final demand.

Rearranging the equation above to solve for final demand, we obtain

$$X - AX = Y$$

Since we are interested in observing how a change in final demand (Y) will affect output (X), we then isolate output as well:

$$X(I-A) = Y,$$

where I is the identity matrix, then

$$X = (I-A)^{-1}Y$$

where $(I-A)^{-1}$ is the Leontief inverse matrix which I will describe and use below to study output and employment impacts.

The input-output model I will use here to study the REEE industry is based on the BEA 2006 annual tables at the 65 industry level. The BEA "Total Requirements" table, or Leontief inverse matrix, shows how an increase in demand for a particular industry's product will lead to increased output in that industry and all related industries. For example, an increase in demand for farm products would increase farm output and would also increase output in other industries which provide inputs to the farm industry, such as fertilizer and farm machinery manufacturing. The total requirements table will be an $n \times n$ matrix where n is the number of industries. Once we obtain this table, we can post-multiply it by a vector of final demand (Y) to estimate the effects on output (X). Thus our basic equation to estimate a change in output resulting from a change in final demand is:

$$\Delta X = (I-A)^{-1}\Delta Y$$

Using this impact equation, we can see how changes in alternative types of final demand (personal consumption, private investment, federal government expenditures, or exports) affect output. We can also isolate a change in final demand for one industry or a group of industries (for instance, increased healthcare spending by the federal government) to estimate the economy-wide impacts of such a demand shock.

Estimating Employment Multipliers Using the Input-Output Model

To study the effects on employment, rather than simply output, we convert our Leontief Inverse Matrix into an Employment Requirements Table. This table is used to estimate the number of jobs throughout the economy that are needed, both directly and indirectly, to deliver $1 million of final demand for a specific commodity. In order to create the employment requirements table, we first need to obtain employment/output ratios for each industry in the model. We can obtain gross output by industry as well as full-time-equivalent (FTE) employment by industry from the BEA tables[27]. These data are available at the 3-digit level of the North American Industrial Classification System (NAICS). The industries in the I-O tables are also classified according to NAICS codes,

[27] Gross output and FTE employment are found in the "GDP-by-Industry" files maintained by the BEA and available here: http://www.bea.gov/industry/gdpbyind_data.htm

which is an industrial classification developed jointly by the U.S., Canada, and Mexico, and which has been used since the 1997 Economic Census.

Within the NAICS system, industries are classified at increasing levels of detail, starting with 2-digit sector level detail (e.g. NAICS 11 = Agriculture, forestry, fishing, and hunting), and becoming more detailed with each additional digit (e.g. 111=crop production; 1111=oilseed and grain farming; 11111=soybean farming). The 6-digit level NAICS is the most detailed industry level, and it is this level of detail which is obtained every five years in the Economic Census. From the 6-digit level, industries can be aggregated up to 2-digit through 5-digit levels. The I-O tables are created at three levels: Sector; Summary; and Detail. The sector-level tables correspond to 2-digit NAICS categories and contain 15 industries. The summary-level tables correspond to 3-digit NAICS categories and contain 65 industries. Finally the benchmark, or detailed tables, correspond to the 5-digit NAICS categories and contain 477 industries.

Here I choose to work with the summary level tables (65-industry) for two reasons. First, the size of these tables is more tractable and this will become an important factor as I integrate new data into the existing tables (discussed in subsequent chapters); and secondly, the benchmark (477-industry) tables are only produced every 5 years, and the most recent version available is from 2002 (the tables are released with a 5-year lag due to the intensive activity of converting statistics from various sources into the I-O tables). The summary tables are updated annually, as described above, and therefore tables from more recent years are available. I will work with the 2006 summary-level I-O tables.

In their national industry accounts, the BEA provides estimates of gross output by industry in 2006 as well as full-time-equivalent (FTE) employment by industry in 2006 at the 3-digit NAICS level of detail, which is the level we need in order to generate employment/output ratios for each of the 65 industries in the BEA input-output tables. I generate an employment/output ratio for each industry, which is simply the total FTE employment for each industry divided by that industry's gross output in the same year, in this case 2006. I then form a diagonal 65×65 matrix with the employment/output ratios along the diagonal and zeros elsewhere, which I call "e."

To create the employment requirements table, E, I take the diagonal matrix of employment/output ratios, e, and post-multiply it by the Leontief inverse matrix, or total requirements table, as follows:

$$E = e(I-A)^{-1}$$

Where $(I-A)^{-1}$ is the Leontief inverse table and e is the diagonal matrix, both of which have the dimension 65×65.

The employment requirements table shows us both the number of jobs directly created and indirectly created, as a result of demand for a particular industry's product. For example, if demand for farm production is $1million, we can immediately see both the number of farm industry jobs (direct jobs) supported by this demand, as well as the number of jobs supported in other industries such as fertilizer and farm equipment which supply inputs to farms (indirect jobs).

The employment requirements table is the foundation of my analysis, and I will use it to see how changes in spending can affect jobs throughout the economy. While the

Leontief inverse matrix yields output requirements and an output multiplier, the employment requirements table yields employment requirements and an employment multiplier. Each industry will have a unique multiplier.

We can use this framework to see how an increase in spending in any industry (an exogenous increase in demand, which could result either from private or public spending) will generate jobs. The basic impact equations are:

$\Delta X = (I-A)^{-1}\Delta Y$ (to measure change in output); and

$\Delta X = E\Delta Y$ (to measure change in employment).

The employment multipliers from this static model include both direct and indirect employment resulting from a given type of demand. The direct employment effects are found along the diagonal of the E matrix. The indirect effects for a given industry are the sum of all of the values in a column of the E matrix, minus the direct value along the diagonal. In table 3 I present employment multipliers from a selection of industries within the standard 65-industry BEA I-O model from 2006.

As we see from table 3, the employment multipliers for different industries within the I-O model can vary quite a bit, with a low of 0.64 direct jobs per $1 million demand in oil and gas extraction, a very capital-intensive industry, to higher values such as the 13.80 jobs/$1million found in administrative and support services, a much more labor-intensive industry. As described in detail above, the employment multipliers are the result of two factors: employment/output ratios and inter-industry transactions (captured in the Leontief inverse matrix).

Mathematically, it is clear that the multiplier of a given industry will be large if the employment/output ratio is high, if the level of inter-industry transactions (output multiplier) is high, or if some combination of the two occurs. More generally, however, we can trace the causes of differences in employment multipliers to three main reasons: labor intensity; domestic content; and compensation to workers. Labor intensity is captured by the employment/output ratio. In comparison to industries that are capital-intensive, labor-intensive industries will employ a greater number of FTE workers for the same level of output. Secondly, an industry will have a higher employment multiplier the higher its share of domestically-produced inputs is. This is captured within the inter-industry table. A higher domestic content implies that more output, and therefore more employment, is created within the domestic economy, rather than being imported or outsourced and creating output and employment in foreign economies. Since the inter-industry table measures the extent to which domestic industries supply goods and services to each other, a higher domestic content will be captured in this table. Thirdly, all else equal an industry will have a higher employment multiplier if average compensation is lower. For example, if $1 million in final demand generates $600,000 in total compensation (and the remainder in other inputs), and average compensation is $30,000, then 20 FTE workers will be employed. However, if the $600,000 is paid out to workers earning on average $60,000, then only 10 FTE workers will be employed. Thus in general any difference between industries' employment multipliers can be traced to some combination of differences in labor intensity, domestic content, and worker compensation. Industries with higher labor intensity, higher domestic content, and lower compensation, will have higher employment multipliers.

Assumptions Embodied in the Input-Output Model

Miller and Blair (1985) note that the two main assumptions in input-output tables are those of fixed technical coefficients and fixed input proportions. Fixed technical coefficients means that the inter-industry flows from industry *i* to industry *j* depend entirely on the output of industry *j*. In other words, if the output of industry *j* doubles, its input from industry *i* will also double. Fixed proportions implies that industry *j* will use the same mix of inputs from all industries even as demand increases for industry *j*'s output. That is, the production function, which is a Leontief minimization function, is homogenous. Rather than a classical production function which assumes diminishing marginal returns, the Leontief production function assumes constant returns to scale. The returns are fixed by technology, and technology is assumed to remain constant as output grows. The BEA refers to these two assumptions as the principles of homogeneity and proportionality.

We must keep these assumptions in mind when conducting any impact analysis with the I-O tables. First, this suggests that I-O tables are best suited to studying the current state of the economy and making short-term projections and we should therefore exercise caution when using I-O models to conduct long-range forecasts. In the long-term, we would expect technological change to occur, which would change the production function and therefore the factor proportions. Furthermore, the assumption of constant returns to scale is relevant only for relatively small changes in levels of output. If an industry increases output by, say, 5 or 10 percent, we might be able to assume constant returns to scale. But a doubling of the size of the industry, such as we might expect to occur with renewable energy, will no doubt lead to changes in the returns to scale alongside changes in technology. Thus, we should exercise caution in using input-output models for forecasting purposes, and any forecasts we may want to conduct in future work should no doubt include integrated models built on a dynamic input-output framework which incorporates changes in production functions.

Furthermore, because the Census is an "economic snapshot," the resulting I-O tables themselves are static. Thus, we must be aware of not only homogeneity and proportionality, but also of fixed prices. If, over time, input prices change, then we would expect industries to substitute cheaper inputs for the more expensive inputs.

The limitations of the input-output model lie in these three assumptions (homogeneity, proportionality, and fixed prices) which are of course made for simplification as we know that no industry operates in this type of environment. Its strength, however, lies in the simplicity of the model and the relatively limited number of assumptions in comparison to more complex general equilibrium models which typically rely on a far greater number of assumptions.[28] Richardson (1972) says that part of the appeal of the I-O model is that it is "value-free" and "neutral" and thus is useful for economic impact studies in a wide variety of settings – from capitalist to planned economies.

Input-output tables can essentially be used in one of three ways: To determine the current state of economic interactions (static); to change assumptions regarding production functions or prices, or to change final demand (comparative static); or to

[28] For example, typical assumptions in CGE include profit-maximization, perfect competition, market-clearing conditions, production at full capacity, and full employment.

incorporate technological change or permit expansion of the economy by introducing capital coefficients into the framework (dynamic). Here we will be using the input-output model for comparative static analysis. Namely, we will study the employment effects of an increase in final demand for REEE products and services.

<u>Creating "Synthetic" Industries in the I-O Model</u>

Background and Motivation

As previously noted, within the 65 industries in the BEA there is no 'Renewable Energy' or 'Energy Efficiency' industry. The only energy-related industries which are identified in the BEA I-O model are oil/gas extraction, coal mining, support services for these extraction activities, power generation and distribution, and various petroleum- or coal-based manufacturing activities. Renewable energy technologies such as wind, solar, biomass, geothermal, and so on, are not explicitly identified. Energy efficiency industries such as building weatherization, "Smart Grid"[29], energy-efficient appliances, and so on are also not explicitly identified. Nonetheless, the activities of these industries are captured implicitly in the input-output accounts. For example, the manufacture of hardware and electrical equipment used for solar panels are categorized respectively in the hardware and electrical equipment industries. If we can thus identify the various

[29] "Smart Grid" is a term used to describe a modernized electricity transmission infrastructure which relies on information-technology to increase reliability and reduce demand of the electrical grid system. The Smart-Grid is more interactive and distributed than the current electrical grid in that it allows end-users to interface with power use through 'Smart Meters' and allows for more de-centralized power production (such as wind and solar) to be distributed to users. For more information, see for example publications by the U.S. Dept. of Energy's Office of Electricity & Energy Reliability, accessible here: http://www.oe.energy.gov/smartgrid.htm.

components and their weights that make up the REEE industry, we can study the impact of increased demand for REEE products and services. The methodology for what I am calling the 'synthetic industry approach' is presented in Miller and Blair (1985).

The synthetic industry approach may serve as a placeholder strategy or a viable alternative strategy to gathering survey data and explicitly identifying the REEE industry and expanding/updating the existing BEA I-O tables, which I will discuss in chapters four and five. The integrated approach presented in subsequent chapters models both forward and backward linkages between various industries, thus the REEE industry is both a consumer and producer of goods and services in the integrated approach. In the synthetic approach presented here, however, we simulate an exogenous increase in final demand for the goods and services used in the REEE industry. Thus here the REEE industry is essentially a consumer of goods and services (all of the inputs that go into the manufacture of wind turbines, for example), but is not a producer from which other industries purchase. Therefore we only capture linkages in one direction and cannot capture the full set of economic interactions. After presenting this approach below, and the integrated approach in chapter 5, I will discuss the results and merits of each method in chapter 6.

The motivation and precedent for using the synthetic industry strategy to study renewable energy is developed in the EWEA's study of the European Wind market (European Wind Energy Association, 2004). This comprehensive study, discussed earlier, includes information on the components and costs of wind turbine production as well as employment in the wind energy industry. The authors undertook a survey of various European firms in the wind energy industry. Through this process they gathered data on the direct employment in wind energy firms, along with the data that would allow them to use EuroStat's Input-Output accounts to measure indirect employment. To do so, they categorize the wind energy components into industries which exist in the I-O tables and use the industry-appropriate employment multiplier to arrive at the figure for indirect employment in wind turbine manufacturing. They conduct similar exercises for installation and maintenance.

The EWEA methodology not only motivates the survey which we conducted and will discuss below, but also offers guidance as to how to use existing I-O tables along with information on REEE components to derive REEE employment multipliers. The EWEA publication shows that for wind turbine manufacturing, the various components and weights are as follows:

37%	machinery
26%	construction
12%	fabricated metal products
12%	plastic products
7%	scientific/technical services
3%	mechanical power transmission equipment
3%	electronic connector equipment

Using these weights along with our basic employment impact equation,

$$\Delta X = E\Delta Y$$

we can analyze the effects of an increase in demand for wind turbine production. If our change in demand, ΔY, is \$1 million, then the increased demand for industrial production in the I-O model is:

$370,000	machinery
$260,000	construction
$120,000	fabricated metal products
$120,000	plastic products
$ 70,000	scientific/technical services
$ 3,000	mechanical power transmission equipment
$ 3,000	electronic connector equipment

Using these industries and spending amounts, we can thus estimate the effects on employment (or on output) of a $1 million increase in demand for wind energy production. These above shares include the manufacture of wind turbines, which the EWEA estimates to be 74-82% of the total cost of new wind power, as well as associated construction costs and other services. Similarly, we can use information we gather about the component costs of various REEE industries to create a final demand vector (or change in final demand, ΔY). This will allow us to study the effects of expanding the REEE industry without having an REEE industry explicitly identified in the I-O tables.

Recent Applications

To my knowledge, the only studies which have used this approach – the analysis of synthetic REEE industries using the I-O model – have been those co-authored by myself along with other economists at the Political Economy Research Institute (PERI) at the University of Massachusetts, Amherst[30]. In the PERI studies we have used this approach to model various clean energy investments both in the U.S. (at the national, regional, and local levels) and in Ontario, Canada. We have also used this framework to

[30] See, for example, Pollin, Heintz & Garrett-Peltier (2009, June); Pollin and Garrett-Peltier (2009, April); or Pollin et al (2008, Sept.).

model other investment or spending programs such as infrastructure and military spending. We return to these studies below.

Other authors have conducted similar exercises but without using all parts of this methodology. For example, the Renewable Energy Policy Project conducted a report for the state of Ohio in which they identify all of the components of various manufactured clean energy technologies (wind, solar, geothermal, biomass), along with investment amounts, to forecast employment growth in each of those industries based on certain funding levels (Sterzinger & Svrcek, 2005). However, the authors of this report did not use the components and costs in tandem with the input-output accounts, but rather used a rule-of-thumb number of jobs for all of the industries (3000 FTE jobs per $1 billion investment) and applied that to the spending in each component industry. Thus the only industry-specific employment effects result from differences in spending levels per industry, not differences in labor intensity or production functions.

Using the input-output model along with the spending-by-industry information yields richer detail and arguably more accurate estimates, since it allows us to estimate industry-specific employment outcomes in addition to economy-wide outcomes. Whereas the Sterzinger & Svrcek paper uses a rule-of-thumb 3000 FTE jobs per $1 billion investment for all of the component industries, within the I-O model we could estimate a jobs/dollar value for electronic goods, for electrical equipment, for fabricated metal, and so on. We could then use a weighted-average jobs/dollar that would reflect both the employment and spending specific to producing wind turbine components. This may be lower or higher than the Sterzinger & Svrcek rule-of-thumb, but it is certainly more rigorously derived, since the production functions of various wind energy components are likely to differ from one component industry to another, and therefore our employment estimates will be more accurate than a rule-of-thumb estimate.

Two examples of papers which use the synthetic industry approach to estimate the employment effects of REEE investments are “The Economic Benefits of Investing in Clean Energy” (Pollin, Heintz, & Garrett-Peltier, 2009) and “The U.S. Employment Effects of Military And Domestic Spending Priorities” (Pollin & Garrett-Peltier, 2009). In each of these papers, we use alternative specifications for green investments in order to compare them to various other domestic spending programs. In the first paper, we compare the job creation effects of various energy efficiency and renewable energy investments (building retrofits, mass transit/rail, smart grid, wind, solar, and biomass) to fossil fuel investments (oil/natural gas and coal). The job creation estimates from each $1 million investment are presented in figure 1. In order to obtain these estimates of direct and indirect job estimates, we use an input-output model and define the ‘synthetic’ REEE industries and fossil fuel industries as presented in figure 2.

Thus we use the synthetic industry approach to analyze REEE industries within the I-O model and generate employment estimates that are directly comparable with fossil fuel industries. In the 2009 paper by Pollin and Garrett-Peltier, we compare clean energy investments with a variety of domestic spending areas such as military spending, education, health care, and tax cuts for personal consumption. While military spending, education, health care, and personal consumption are all sectors identified within the standard I-O model, the clean energy industry of course is not. However, the synthetic industry approach allows us to estimate the employment impacts of clean energy in a manner consistent with developing our estimates for the other spending areas. Our synthetic "clean energy" industry is the same as the "green program" in previous work, such as the 2009 Pollin, Heintz, Garrett-Peltier paper previously mentioned. The "green program" or "clean energy" industry in these works consists of 40% building weatherization, 20% mass transit/rail, and 10% each of smart grid, wind, solar, and biomass investments. Each of these industries was in turn developed using the synthetic industry approach with the weights as listed in the above figure.

Testing the Validity of the Synthetic Industry Approach

The synthetic industry approach allows us to perform impact analysis for industries which do not currently exist in the input-output model. To my knowledge, there are no formal tests we can use to gauge the validity of this technique. There are other methods we could use, however, to see if our estimates are reliable. Two such methods include surveying/interviewing large numbers of firms in the industry in question, and performing specification tests with our synthetic industry components and weights.

In the first instance, we would use a survey of industry members to assess whether our employment estimates derived through the synthetic industry approach correspond with reported employment in REEE businesses and organizations. That is, if we predict that $1 million demand for wind turbines will generate X number of jobs in wind production, do wind turbine manufacturers actually employ X number of workers for each $1 million in revenue? Since the input-output model is based on industry aggregates, we would need to survey a large number of firms to find the average values among them and to see if they correspond with our model's predictions. In chapter six I will perform such a test. However in general it is impractical to gather this survey data to test the synthetic approach, since the approach is generally necessary precisely *because* we do not have sufficient survey data.[31]

The next method we could employ to test the validity of our construction of synthetic industries is to perform various specification tests. That is, we can create alternative specifications for each industry in question by varying the weights of the component industries to see how sensitive the results are to the choice of specification. Since there is no distribution of values, we cannot measure standard deviations or use other population distribution measures. Here I will simply calculate the various impacts generated by alternative specifications, compare those impacts to each other, and then use a rule-of-thumb to determine whether or not the results are sensitive to the specification of the synthetic industry.

I use here the example of the wind industry, created by Pollin, Heintz & Garrett-Peltier (2009) based on the EWEA wind industry weighting scheme (European Wind Energy Association, 2004). I first reconstruct the original direct and indirect multipliers using the original weighting scheme then create two alternative specifications. In the first alternative weighting scheme, I increase the total share of the non-manufacturing industries by ten percentage points and decrease the share of manufacturing industries by

[31] Currently, in fact, PERI researchers are conducting exactly such an exercise with data from recipients of Dept of Energy grants and contracts awarded as part of the American Recovery and Reinvestment Act of 2009. PERI researchers used an input-output model to estimate employment resulting from a variety of Recovery Act programs, and now the awardees are reporting jobs created/maintained by these programs, allowing the researchers to compare estimates to reported job counts. However, typically this type of data is not available to test the validity of I-O employment estimates.

ten percentage points. In the second alternative specification, I increase the share of manufacturing industries and decrease non-manufacturing, each by ten percentage points. The alternative weights and resulting employment impacts are presented in table 4.

We see from table 4 that the original employment impact for wind (direct plus indirect jobs per $1 million) is 9.19. The first alternative specification, in which I increase the weight of manufacturing industries by 10 percentage points and decrease the weight of non-manufacturing industries by the same, results in a change in employment of only 1.6 percent, from 9.19 to 9.34 total jobs per $1 million. Likewise, when I decrease the share of manufacturing and increase non-manufacturing by 10 percentage points, employment changes by only 1.7 percent, from 9.19 to 9.03. A significant change in the specification of the wind industry, therefore, results in a relatively insignificant change in the employment outcome. Thus we can consider the results of this example to be robust, and we can use this type of specification testing to check the robustness of other synthetically created industries.

The specification test described above is an example of a method to check the robustness of our results. Here I used the example of the EWEA wind industry. In Chapter 6, I will perform this test with the synthetic REEE industries as I define them, and discuss the implications of the specification test and robustness of my results.

CHAPTER 4

SURVEY OF RENEWABLE ENERGY AND ENERGY EFFICIENCY FIRMS

Background and Motivation for Survey

As mentioned above, the input-output accounts maintained by the Bureau of Economic Analysis (BEA) of the U.S. Department of Commerce currently do not identify clean energy industries as such. Industries such as solar, wind, building retrofitting and many others are not uniquely identified by industrial codes, and therefore it is not possible to analyze them in a manner congruent with the analysis of other industries which do have industrial codes. Renewable energy and energy efficiency industries are, however, part of the economic activity of the U.S. economy. Until now, this activity has been categorized along with other similar goods or service-providing industries. So, for example, gear boxes used to produce wind turbines are grouped with other types of gear boxes, but are not identifiable as part of the 'wind' industry per se. This makes it difficult to compare the output and employment of the wind industry to the output and employment of, say, coal or oil.

One method for overcoming this limitation with the BEA's input-output tables is to collect data on purchases and supplies (inputs and outputs) from firms in the REEE industry. By doing so, it is possible to identify the components of the current I-O tables that could be re-categorized as REEE. The general method, which will be elaborated upon below, is to disaggregate the industries which contain some component of REEE input or output, then reorganize the I-O tables with a new REEE industry explicitly identified. A survey of firms in the REEE industry, which elicits data on their purchases and sales, allows us to perform this reorganization of the input-output tables.

<u>Selecting Sample</u>

Sample Size

The Input-Output tables maintained by the BEA are based on a nationwide sample of firms, and therefore in choosing my sample of REEE firms to survey I selected from a national pool. Following Salant and Dillman (1994), I first identified the target population (REEE firms), then compiled a population list, then chose a sample from this population. In this case the population of all REEE firms nationwide was too large to assemble in a reasonable time-frame, and I therefore compiled a smaller population list of about 1,000 firms and then chose a random sample of these firms (both of which will be described below).

In deciding how large to make the sample, I once again draw from Salant and Dillman (1994) who list various sample sizes and sampling errors for a variety of population sizes. I do not initially know the number of firms in the population, and therefore must initially hypothesize the size of the population in order to choose a sample which is representative and statistically significant. Given that my initial database consists of 1,000 firms, and that it is not inclusive of the entire population, I can make a reasonable assumption that the population consists of at least 10,000 firms, and most likely more than that. For a 95 percent confidence level, at greater than 10,000 firms, the sample size needed for my results to fall within a ±10% sampling error is 96. To fall within a ±5% sampling error I would need a sample of 370 firms. If the population is larger than 10,000, the sample size needed to remain within these sampling errors grows only slightly. For example, a population of 1,000,000 requires the same 96 for the ±10% sampling error, and 384 (rather than 370) to fall within a ±5% sampling error. Thus in conducting the survey I would ideally like close to 400 useable responses, however with 100 or so useable responses I can still have 95 percent confidence that my sample has no more than ten percent sampling error. The Salant and Dillman table is reproduced as table 5, with the values relevant to my survey in bold.

Assembling Population List

In order to assemble my population list, I used a variety of sources in which REEE firms either self-identified as such or were externally identified as a REEE firm. The majority of my database was drawn from Dun & Bradstreet, a global database containing more than 140 million business records. The D&B database allows users to search by industrial codes (both the North American Industry Classification System, or NAICS, and the Standard Industrial Classification, or SIC, that preceded it). D&B also allows for searches of businesses by name, keyword, location, and other criteria.

I compiled about forty percent of my database by using these various search criteria to search for businesses whose names included words such as wind, solar, biomass, biofuel, conservation, hydroelectric, renewable, sustainable, green, energy, efficiency, as well as variations of those words. I also searched by SIC code, which interestingly identifies some renewable energy categories (such as solar hot water heaters), whereas the NAICS coding system that replaced SIC no longer identifies these categories. For example, the SIC code 52110303 is for solar heating equipment sales and the code 36740305 is for solar cell manufacturing. By using these SIC codes, among others, I was able to search for firms within these categories. While the SIC code is not used to classify industries within the input-output tables, it does help us identify firms that have been in business long enough to have an SIC code (which was used until the early 1990's and replaced by NAICS), and it also allows us to match the SIC codes for renewable technologies with currently used NAICS codes. So, for example, a firm which used code SIC 36740305 (for solar cell manufacturing) is now categorized as NAICS 334413 (semiconductor and related device manufacturing). I will return to this issue of re-categorization below.

Using the D&B database to search by word and industrial code allowed me to assemble a population list of approximately 400 businesses. In order to compile a larger population list I supplemented this initial list with businesses listed in membership organization publications. These included the membership directories of the Northeast Sustainable Energy Association (NESEA), the Midwest Renewable Energy Association (MREA), the National Directory of Sustainable Energy Companies, and the Sustainable Energy Coalition. I added the names and contact information of all of the companies and organizations listed within these publications, then sorted the database to remove duplicates, and ended with a population list of approximately 1,000 REEE firms and organizations. Approximately 75 percent of these firms were small businesses, with employment of 50 or less. The firms were distributed geographically across the U.S., with 47 states (including Alaska and Hawaii) represented in the list.

Random Sample Selection

In order to draw a random sample from this database, I sorted the entries by state and then selected 2 out of every 3 entries (alphabetically), for an initial sample list of 650 firms. I opted for this size knowing that some firms might no longer exist or might be unwilling or unable to answer the survey. I also initially aimed to get responses from close to 400 firms so that I would have a sampling error of ±5% at the 95 percent confidence level.

Enlarging Sample

I conducted the survey from January through July 2008 with the assistance of a team of telephone interviewers. By February, after having contacted – or attempted to contact - everyone in our initial list, we found the need to expand the survey sample. While my initial sample comprised about 2/3 of the population list, I decided at this point to expand the survey to the full population list of about 1,000 firms, thus including the 1/3 of firms that I had not initially selected. This need arose for two reasons. First, we were unable to contact some of the firms in the database, either because they were no longer in business or we were unable to establish contact after repeated phone and email attempts. Secondly, many of the firms we did contact were unwilling or unable to complete the questionnaire. In some cases this was because the firm was very small and did not have the time or personnel to complete the questionnaire. In other cases the firms had the time and personnel but were unwilling to reveal financial information. Some of the reasons stated for this reluctance included that the firm was about to make a public stock offering or was otherwise concerned about confidentiality and was therefore uncomfortable releasing sensitive financial information to interviewers. Thus over the first few months of conducting the survey we expanded the contact list (until the sample list was equal to the population list) and aimed to receive at least 100 useable surveys, which would put us in the ±10% sampling error range. Of the initial list of 1,000 firms, about half were unavailable or unable/unwilling to complete the questionnaire. We thus sent out approximately 500 surveys to people who expressed an interest or willingness to complete and return the questionnaire.

Questionnaire Design

Questionnaire Content

Input-output tables compiled by the Bureau of Economic Analysis (BEA) are drawn from multiple data sources, including the Economic Census conducted every 5 years (in years ending in 2 and 7) by the Census Bureau. The Economic Census collects data from about 5 million business establishments nationwide. This data set is supplemented by data from administrative records (through various other government agencies) representing 14 million businesses without paid employees and 1.5 million small businesses. In years between the Economic Census years, the Census Bureau administers other surveys, such as the Annual Survey of Manufactures and the Business Expenses Survey (Horowitz & Planting, 2006). I based the design of my survey on these annual surveys conducted by the Census Bureau.

The Census Bureau surveys ask respondents to categorize their expenses under the following categories:

-Employee compensation
-Purchased materials and supplies for own use (industry specific)
-Utilities costs
-Purchased services (industry specific)
-Other operating expenses
-Interest expenses

This survey thus includes information about the input costs, by industry, which firms face. I included all of these input categories in the survey. In order to capture output (sales) as well as job quality (in terms of salary and benefits) as well as specific occupations, I added the following sections to my survey:

-Sales (industry specific)
-Subsidies and other public support received
-Employment (total)
-Occupations (with average hours worked per week in each occupation)
-Energy purchases
-Energy production for sale and for own use

An example of the survey questionnaire is included in the appendix.

Questionnaire Form

The initial design of the questionnaire corresponded with that of the Census Bureau surveys. That is, it was a downloadable PDF file that respondents could either fill in by hand or fill in electronically if they have the appropriate software (Adobe Acrobat Writer). However, in testing the questionnaire (see below) it became clear that it would be easier for respondents to fill out the questionnaire electronically in a spreadsheet program such as Microsoft Excel. I thus designed an identical version of the survey for Excel, and we sent that version electronically if respondents expressed such a preference, or sent the hardcopy version if the respondent expressed a preference to receive and fill in a paper form.

Testing Questionnaire

We identified a few individuals with the REEE community who were willing to fill out a draft version on the questionnaire and provide feedback on how it could be improved. In November and December of 2007, 5 individuals representing different REEE firms completed the test questionnaires. Based on their responses, I made some modifications to the design of the form, including adding the Excel version, rewording some questions, and rearranging the order of some items. The final version was ready to implement in January 2008.

Responses

Between January 2008 and July 2008, we sent out approximately 500 surveys to REEE firms across the U.S. Firms were first contacted by phone to establish that they were indeed an REEE firm and to explain the survey and gauge their interest in completing a questionnaire. If they expressed a willingness to do so, they were sent either a hard-copy version or Excel version of the questionnaire, and assigned a deadline by which to return it (usually 2-4 weeks hence). In almost all cases, it was necessary to follow up with the respondent either by phone or email or both to ensure that they return the questionnaire. Due to initially low response rates, we also eventually instituted a financial incentive for completing the survey, including a small cash payment for survey completion and entry into a lottery for a larger cash payment.[32] Over the six months of the survey, we received just over 100 full useable questionnaires. This is a 20% response rate, and puts us within a ±10% sampling error within a 95 percent confidence interval.[33]

In table 6 we see that about one-quarter of the responses came from firms in the green building and retrofitting industry, close to one-third were in energy services (including design, marketing, advocacy, and so on), and of the renewable energy sectors, biomass and solar are well represented while wind is under-represented.

While I noted above that our response rate of 20% is not necessarily correlated with non-response bias, I must nonetheless consider that non-response bias may be present in the data. We see in table 6 that the wind firms are under-represented in relation to other REEE firms who completed the questionnaire. This may present some bias in the data as we assume that the population of renewable energy firms is well represented by our survey sample. Likewise, within each category there may be bias resulting from the non-response of firms with certain characteristics, such as larger firms or firms which are publicly traded. If the inter-industry linkages of the non-respondents

---

[32] See for example (Yu & Cooper, 1983) for an analysis of survey response rates. They find that "studies which manipulated the presence versus absence of monetary incentives found incentives to be superior (50.5% versus 35.2%; $\chi 2 = 188.1$, $p < .001$)" and that the amount of the incentive paid had a strong and positive effect on the response rate (p. 39).

[33] As discussed in Keeter et al (2006), a 20 percent response rate is not necessarily less effective than a higher response rate in reducing nonresponse bias. In fact, through two separate experiments and in reviewing other experiments, the authors found "compelling evidence that response rate is not necessarily an indicator of survey quality (p. 761)." Further, Groves (2006) finds that there is no minimum response rate below which nonresponse bias appears and no maximum rate beyond which nonresponse bias ceases to exist.

differ significantly from those of the respondents, our survey results will be biased. However, without being able to access public records or other financial data of the non-respondents (for example, Economic Census data), I am unable to know whether any non-response bias exists in our data. Therefore I will cautiously proceed with the assumption that the responses from the survey sample are representative of the population of REEE firms in the U.S. and that no significant bias exists in my data.

Next, in order to integrate my survey results into the input-output tables (discussed in the next section), I chose to group responses into larger categories so that each category would have large sample properties. I thus chose Energy Services, Renewable Energy, and Green Building/Retrofitting as the 3 industrial groupings. Grouping the responses accordingly yields the results shown in table 7.

"Renewable Energy" includes biomass, solar, wind, hydroelectric, and sales/installation of renewable energy equipment. "Energy Services" include the same categories shown in the preceding table. "Green Building and Retrofitting" includes green design (architecture and engineering), new construction and repair construction, construction education, and EE installation. Having grouped the survey responses into these categories, I am then able to integrate the survey data into the BEA's 65-industry input-output tables either as one new REEE industry or as 3 separate industries.

CHAPTER 5

INTEGRATING SURVEY DATA

In order to integrate the survey data into the input-output tables maintained by the BEA, I had to make a series of adjustments to ensure that the data were consistent. This involved three steps. The first was to eliminate any questionnaires in which the sales and purchases sections were not filled in. The next step was to convert all of the data to the same base year, which involved making adjustments for both inflation and growth. The final step was to scale the survey results to the size of the national REEE industry.

Survey respondents were asked to provide data for the calendar year 2005, which at the time of the survey was the most recent BEA data set available for use, and we therefore wanted to collect data from firms for that same time period. However, knowing that some firms might have been established after January 2005, or might not have readily accessible data from 2005, we allowed them to provide 2006 or 2007 data, provided that they gave a full calendar-year of data and declared the year for which they reported data. Thus, some firms gave 2005 data while others provided data for 2006 or 2007. By the time we collected, processed, and started integrating the data, 2006 BEA input-output tables were available. I therefore converted all of our survey data to 2006 in order to integrate the data into the most recent BEA tables.

Converting data to consistent base year

Adjusting for Inflation

The first step in converting the 2005 and 2007 data into a 2006 base year was to adjust for inflation, so that all of the survey data was in real, rather than nominal, prices. The input-output tables use producer prices for the dollar value of goods and services. Therefore I follow the BEA methodology and use the Producer Price Index (PPI) to adjust all of the 2005 and 2007 data to 2006 dollar values (Kim, Davis, Jacobson, & Lyndaker, 2008). The U.S. Bureau of Labor Statistics (BLS) maintains industry-specific PPIs for most of the industries in our model.[34] For those industries which did not have specific PPIs, I used the average PPI for the sector. So, for example, if a certain service industry did not have a unique PPI, I used the average PPI for all service industries (this was a straight average, based on all the available PPIs).

Adjusting for Growth

Having adjusted for inflation, the next step in converting the data to the same base year is to adjust for growth. Many industries within renewable energy and energy efficiency have experienced rapid growth in the past few years. Since the growth rates are non-negligible, I needed to adjust the data according to industry-specific growth rates. I make the assumption here that each firm reporting 2005 data had the same growth rate as the average for their subset of the REEE industry. For example, I adjust the data for each solar industry firm by the growth rate for the solar industry. I make a similar assumption for firms reporting 2007 data. I therefore make an upward adjustment to

[34] http://www.bls.gov/ppi/

2005 data and a downward adjustment to 2007 data based on each industry's growth rate in this time period. Hence if I have 2005 data from firm A, 2006 data from firm B, and 2007 data from firm C, I assume that firm A grows by the relevant rate (in table 8) between 2005 and 2006, adjust their survey responses accordingly, then use this adjusted data. Similarly, I assume that firm C had grown by its industry's growth rate between 2006 and 2007, and therefore I shrink firm C's 2007 survey responses to reflect that growth and make the data comparable to 2006 data from other firms. The industries and growth rates are shown in table 8.

The growth rates in table 8 were taken from a variety of publications. In some cases, 2 or 3 publications had roughly the same growth rate for an industry. In many cases, however, 2 publications might have similar rates and a 3rd publication had quite a different rate. In these cases, I use the rate that appeared most often, or the average between two similar rates. For example, wind averaged almost 39% annual growth from 2005-2007 using EIA data, but 26% annual growth using both DOE-EERE and ACORE data. Therefore I report the growth rate of 26% here. In the cases where EIA growth rates were used, I calculate annual growth rates based on the levels provided in the EIA tables. Other data sources and publications explicitly listed annual growth rates or average annual growth rates for the period in question. While the growth rates listed in table 8 appear to be quite large, we must remember that these industries are starting from low levels and therefore even rapid growth in the range of 22-31% is only a small change in level for these industries.

The six REEE categories in table 8 correspond to the categories into which I initially grouped the survey responses in order to adjust the firm-level data by the appropriate growth rate. I first aggregated all of the survey responses on purchases and sales (adjusted for inflation) into these six categories, then adjusted each category's data set by the corresponding growth rate from table 8, thus creating a survey data set that was in a consistent base year of 2006. From these six REEE categories, adjusted for both inflation and growth, I am then able to aggregate the survey responses into one complete REEE industry or into 3 separate and distinct REEE industries.

Scaling Survey Responses to National Industry Level

The survey data represents only a portion of the full population of REEE firms and organizations. The next step before integrating the survey data into the I-O tables is to scale the results up to the size of the national REEE industry, since I am integrating these results into national I-O tables. However, this presents a challenge, since there is no consistent data set for the national REEE industry. I therefore consulted multiple publications for estimates of the size of this industry, and compared the results to arrive at a plausible number that I could use to scale my results upward. When I integrate the data (described below), I do so in two ways: by expanding the tables to include one REEE industry; and by expanding the tables to include three industries (Renewable Energy, Energy Services, and Green Building/Retrofitting). Therefore in scaling the survey results to the national industry size, I first find a scale factor for the REEE industry as a whole. I must assume here that REEE firms are sufficiently well represented in the survey sample and that the scaling factor applied to the REEE industry as a whole is appropriate nonetheless for its comprising industries.

While there has been a recent surge in clean-energy related publications, the attempts to measure and catalog the full scope of the REEE industry in the U.S. are few. To date, the two publications that most effectively do so (and that offer the most guidance in scaling my survey results) are "The Size of the U.S. Energy Efficiency Market: Generating a More Complete Picture" (Ehrhardt-Martinez & Laitner, 2008), and "Defining, Estimating, and Forecasting the Renewable Energy Industries in the U.S. and Colorado" (American Solar Energy Society and Management Information Services, Inc. , 2008). The first publication (ACEEE) measures the size and scope of the energy efficiency (EE) market, while the second (ASES/MIS) measures both EE and renewable energy (RE). The ACEEE publication is notably smaller in scope, since it focuses only on energy efficiency and does not include renewable energy. The ASES/MIS study is larger in scope both since it includes RE in addition to EE, and it takes a more expansive definition of the EE (discussed below). The ASES/MIS study can therefore be seen as an upper bound of the size of the REEE industry. However, there are commonalities between these two studies – there are many energy efficiency industries in common. I can thus compare the EE estimates between these publications where they do overlap, and if I find that the size of the industries in common are comparable, then each study will lend some degree of validity to the other. Unfortunately I am not able to triangulate my results or compare these estimates to other studies beyond these two, since other studies on the size and scope of the REEE industry simply do not exist at this time. Nevertheless, if these studies support each other's estimates of the EE industry, then we have a starting point for assessing the reliability of the estimates. We will find below that in fact, there is very clear overlap and that both studies derive quite similar estimates of the sizes of the industries where they do overlap. Therefore we can be reasonably confident in using their results to scale our survey responses. Since the Erhardt-Martinez and Laitner study is limited to EE, and only the ASES/MIS study captures both EE and RE, we use the combined REEE size from the ASES/MIS report to scale our survey results.

Ehrhardt-Martinez and Laitner write that "the disaggregated nature of the energy efficiency market, combined with the lack of concerted data collection efforts, has made it exceedingly difficult to assemble a holistic picture of the contributions of efficiency (2008, p. 7)." The authors define energy efficiency as using less energy to meet the same (or higher) level of energy services. They distinguish this from conservation, which is reducing unnecessary energy use through behavioral change. The categories of energy-efficient investments included in their study are buildings (residential and non-residential), appliances & electronics, the industrial sector, transportation, and utilities. They estimate both total efficiency investments, as well as the "efficiency premium" – the difference in the investment cost of efficient versus inefficient goods or services.

Ehrhardt-Martinez and Laitner estimate that in 2004, total efficiency investments, "across all sectors of the economy, are estimated to be on the order of $300 billion, or three times the size of investments in conventional energy infrastructure [of $100 billion] (2008, p. 13)." Of this, about 14.3% is the efficiency premium. Therefore about $43 billion is the cost of investing in efficiency, above the remaining $257 billion, which is the cost of the equivalent inefficient investment in this set of goods and services.

It is important to note here that in studying the level of employment supported by the efficiency industry as a whole, the full level of investment ($300 billion) is the relevant value, since this investment level generates a certain level of output which in turn requires a certain level of employment. However, if we restrict our attention to studying the net gain in jobs that results from converting from inefficient technologies to efficient technologies, only the efficiency premium, or a small fraction of total efficiency investments, will generate a net gain in jobs. In some cases the job gain might be close to zero, since the labor required to produce an efficient good (such as an EnergyStar washing machine) is not significantly different from the labor required to produce an inefficient good. In scaling the survey results, it is important to establish the full level of REEE investments, not only the premium, since the firms in the survey may be partly or fully devoted to producing energy efficient goods and services. For example, a construction firm who answered a questionnaire might be wholly devoted to performing home weatherization activities, or might partly perform these activities and partly undertake traditional renovations. Therefore the broader scope and level of investment is the relevant value for the purpose of scaling my survey responses to the size of the national REEE industry.

In their study of the national EE industry, Ehrhardt-Martinez and Laitner include a list of estimates of the EE industry published in 11 other studies. Removing the two outlying values, the EE estimates in the other 9 studies are in the range of $170B-$517B in 2004. The average of those values is $282 billion, which is similar to the ACEEE's own estimate of $301.7B. Of this $301.7 billion, 30% of the investment was in the building sector, 29% in appliances and electronics, 25% in the industrial sector, 11% in transportation, and 5% in utilities.

The ASES/MIS estimate of the EE industry is much larger. In 2006, the authors estimate that the REEE industry as a whole had $972.2 billion in revenues, of which $39.2 billion were for Renewable Energy and the other $933 billion were for Energy Efficiency (American Solar Energy Society and Management Information Services, Inc. , 2008). This value of EE revenues far exceeds the ACEEE value at first glance. However, if we decompose the estimates we see that the values of the industries in common between these two studies are actually quite similar.

The ASES/MIS study notes on page 1 that there is not, as yet, a "generally agreed-upon definition of what constitutes the RE&EE 'industry'." Their study is an attempt to define and measure this industry. They take a very inclusive approach to defining REEE and generally consider any job that contributes to a positive environmental impact: "Environmentally-related jobs include those created both directly and indirectly by environmental protection expenditures (p. 9)." The ASES/MIS study includes the private sector, government, non-profit and non-governmental organizations in their measurement of the REEE industry. With regard to energy efficiency, ASES/MIS has an almost identical definition to the one used by ACEEE. They note on page 138 that:

> Energy Efficiency can be conceptualized in two ways:
>
> • Expenditures for goods and services that are made in order to reduce the amount of energy needed for the delivery of a particular energy service (whether or not the investment was made for the expressed intention of achieving energy efficiency)

• The difference in the costs associated with efficient versus inefficient goods and services

In estimating the size of the Renewable Energy industry they include:

Wind
Solar photovoltaics
Solar thermal
Hydroelectric power
Geothermal
Biomass
Fuel cells
Hydrogen
Federal government
Dept. of Energy laboratories
State and local government
Trade and professional associations and NGOs

Their measurement of energy efficiency includes:

Energy Service Companies (ESCO)s
Recycling/re-use/re-manufacturing
Vehicle manufacturing
Household appliance manufacturing
Windows and doors
Computers, copy and fax machines, etc.
TV, video, audio equipment
Heating, ventilation, air-condition (HVAC)
Industrial machinery and related
Miscellaneous durable manufacturing
Nondurable manufacturing
Utilities
Construction
Federal government
State government

Local government
Trade and professional associations and NGOs

This inclusive approach to defining and measuring the REEE industry means that the authors include not only firms and industries that explicitly produce REEE goods or services, but also firms and industries of which a part of the production can be considered renewable or energy efficient. The authors use a variety of data sources and techniques to estimate the size of the EE industry in manufacturing (that is, in areas where EE is not the sole purpose of the firm but is only a subdivision, or a fraction of all appliances sold, for example). For example, to estimate household appliances, they use the penetration estimates of EnergyStar and estimate that 30% of all household lighting and appliances are EnergyStar, then apply the 30% to the size of the household lighting and appliance market as a whole, resulting in an 'efficiency' estimate of $35 billion. As another example, in estimating the size of the efficient vehicle market, they find that small and hybrid cars (earning at least 10 mpg above CAFÉ standards) made up 18% of new vehicle sales in 2007, and then apply the 18% to vehicle manufacturing industries to arrive at a figure for energy-efficient vehicles. Similarly, for all manufacturing industries they estimate a percentage of the industry that is part of EE and apply that percentage to economy-wide revenues and employment for that particular industry.

The scope of the EE industry is much larger in the ASES/MIS paper than the ACEEE paper, with a resulting estimate of $933 billion in the prior paper and $301.7 billion in the latter. However, since the ASES/MIS authors identify the components and values of the EE industry, I can remove those which do not also appear in the ACEEE study to see if the estimates are comparable. The $933 billion in the ASES/MIS estimate includes $275 billion of recycling/re-use, $344 billion of various manufacturing (beyond appliance and HVAC manufacturing), and $9 billion in the government and NGO sector. The ACEEE study includes none of these categories. Without these, the ASES/MIS estimate of the size of the EE industry comes down to $305 billion, quite similar to the $301.7 billion ACEEE estimate and comparable in terms of included industries.

Thus, this comparability serves as a check on the ASES/MIS estimate, which is broader in scope and which includes renewable energy. While the ASES/MIS estimate no doubt has its flaws, and there may eventually be a more accurate estimate of the entire REEE industry in the U.S., to date this estimate is the only one that captures the dollar value of goods and services produced by the REEE industry. While it may be an upper bound, I have shown that it is at least reasonably valid since it can be verified by other estimates that focus specifically on the EE industry. Thus for the purpose of scaling my survey results, I use the ASES/MIS combined estimate for REEE in 2006, which is $972.2 billion in revenues. This value is equal to 4% of the total industry output in the 2006 BEA “make” table, indicating that the REEE industry would make up 4% of industrial output economy-wide.

Methodology for Integrating Results

Incorporating a Single REEE Industry

After compiling the survey responses and organizing the data according to domestic purchases and sales, and international purchases and sales, I use the domestic data to expand the BEA's 65x65 (summary level industry) input-output tables. The BEA provides make and use tables (both of which are commodity x industry) as well as a total requirements table (an industry x industry matrix, also known as the Leontief inverse). I follow the methodology outlined in the United Nations' Handbook of Input-Output Table Compilation and Analysis (1999) as well as in Miller and Blair (1985) to integrate the REEE industry into the BEA tables, which involves the following steps:

First, since the BEA's industry-by-industry table is the Leontief inverse (L), and I need to integrate the survey results into a flow table (F), I had to perform this conversion:

$$L = (I-A)^{-1}$$

$$L^{-1} = I-A$$

$$A = I - L^{-1}$$

A is the coefficient matrix, which is the flow matrix (F) with each cell divided by that industry's total output (A = F/X). Therefore, by multiplying each cell in A by its industry's level of total output (X, available in the BEA use table), I obtain the F matrix. The F matrix is in dollar values (in producers' prices) rather than coefficients.

Once I have the BEA flow table, as well as the domestic REEE purchases and sales, I follow the UN Handbook's methodology for disaggregating the existing I-O table and re-aggregating the results to form an expanded I-O table. In the first instance, I expand the 65x65 industry table to 66x66 to incorporate the addition of a single REEE industry. Subsequently I follow a similar procedure to disaggregate the 65x65 tables and integrate 3 new REEE industries (RE Production and Sales, Energy Services, and Green Building) into a 68x68 table.

The disaggregation entails dividing each of the implicated industries into the portion which is attributable to REEE and the portion which remains as part of the original industry.   I make two assumptions when performing this aggregation. The first is that the inputs (purchases) will be the same for both the REEE portion and the remaining portion of the industry. So, for example, if I disaggregate the construction industry into REEE construction and remaining construction, I assume that the distribution of purchases is the same (for lumber, hardware, etc.). The other assumption I make here is that the consumption pattern (sales to other industries and to final demand) is the same between the REEE industry and the remaining industry.

To perform the disaggregation, for each industry n which is a part of REEE, I multiply the n^{th} column by w_1 and the same n^{th} column by w_2. From one industry (one column) I now have 2 columns with weights w_1 and w_2. Next I do the same for each row n. I multiply the n^{th} row by w_1 and w_2, where w_1 is the weight of the industry apart from REEE and w_2 is the portion of the industry attributable to REEE.   For each industry, I determine w_1 and w_2 by calculating the share of the REEE sales within the total sales for the industry. For example, if the total construction sales for our survey data (after adjustments and scaling) equal $100,000, and the sales for the entire construction industry within the BEA data equal $1,000,000, then $w_1=0.9$ and $w_2=0.1$.

Each cell in the original flow matrix, with a value of f_{ij}, is now split into four cells as a result of this disaggregation:

$$F_{ij} \rightarrow \begin{matrix} w_1 f_{ij} w_1 & w_1 f_{ij} w_2 \\ w_2 f_{ij} w_1 & w_2 f_{ij} w_2 \end{matrix}$$

Disaggregation Matrix – One Industry into Two

We can also write this as F = SfS' where f is the original flow matrix, S is the disaggregation matrix of w's and F is the resulting flow matrix.

Next, I aggregate all of the columns and rows with w_2's (all of the cells which will form the new column and row of the REEE industry). I add all of the $w_1 f_{nn} w_2$ values across the columns of the table to form the new column entries, and all of the $w_2 f_{nn} w_1$ down the rows of the table to form the new row entries. Then the $w_2 f_{nn} w_2$ will form the new cell at the junction of the REEE column and row.

Once I perform this disaggregation and re-aggregation, I should end up with an inter-industry flow table whose total value is the same as the total value of the original flow table (the sum of the cells in F should equal the sum of the cells in f), since I have not added any inputs or output to the economy, I have only reorganized the existing level of inputs and output. Having performed this internal check, I can ensure the validity and accuracy of the above procedure.

Now I have the new flow matrix, F, which I need to convert to a Leontief inverse matrix and then an employment requirements table. First, I convert the flow matrix to a coefficients matrix, A, by dividing each cell in each column by that industry's total output value. I then perform the reverse of the steps above to derive the L matrix. From this, I can calculate output multipliers, which show the dollar value of increased economic activity resulting from a dollar increase in final demand for the product or service of a given industry or set of industries.

To study the effects on employment, rather than simply output, I also need to calculate employment/output ratios. My employment and output data for our original 65 industries are extracted from the BEA.[35] The employment and output data for the REEE industry is the total employment and total output reported by all survey respondents. I generate an employment/output ratio for each industry, and form an employment/output vector, which I call "e." See table 9 for the employment/output ratios of each industry in the model.

To create the employment requirements table, E, I create a 66x66 diagonal matrix, which I call 'e' (the dimensions are 66x66 since we are using 65 industries plus the REEE industry). Each element along the diagonal of e will represent the employment/output ratio unique to the industry in that row and column. Then, to generate the employment requirements table I pre-multiply the Leontief inverse matrix by the diagonal matrix of employment/output ratios as follows:

$$E = e(I-A)^{-1}$$

[35] Gross Output by Industry and Full-Time-Equivalent Employment by Industry are available in the GDP-by-Industry data, found here: http://bea.gov/industry/gdpbyind_data.htm. We use 2006 data.

Where $(I\text{-}A)^{-1}$ is the Leontief inverse table (or total requirements table) and e is the 66x66 matrix with employment/output values along with diagonal and zeros elsewhere.

From the employment requirements table, E, I can calculate the number of full-time- equivalent direct and indirect jobs that result from a given increase in demand. In this case, the table shows the number of jobs created per $1 million of demand.

Incorporating 3 Distinct REEE Industries

The methodology to incorporate 3 new industries into the existing I-O tables, as opposed to only 1, is comparable to the procedure I followed above. While this methodology for integrating multiple industries is not explicitly introduced in the U.N. Handbook, we can nonetheless follow the same series of steps to expand the 65x65 BEA table into a 68x68 table.

I decompose the REEE survey responses into 3 industries: RE production and sales; Energy Services; and Green Building. I group all of the purchases and sales by industry into these three categories, and adjust the results as above, taking into consideration inflation, growth, and the national scale of the industry. Of the total adjusted values for revenues, I find that RE production and sales make up 18%, Energy Services make up 67%, and Green Building 15%. I also calculate employment/output ratios for each of these three industries, based on survey data. These ratios are presented in table 10.

As above, I must first decompose all of the industries within the 65x65 BEA input-output table into the portion attributable to each of these 3 REEE industries and the portion that remains. Now, each cell in the flow matrix (f), instead of being split into four cells (2x2) will be split into 16 cells (4x4). This results because the disaggregation matrix will now consist of weighting values w_1, w_2, w_3, and w_4. Now the original flow matrix (f) will map into the new flow matrix (F) as follows:

$f_{nn} \rightarrow$

$w_1 f_{nn} w_1$	$w_1 f_{nn} w_2$	$w_1 f_{nn} w_3$	$w_1 f_{nn} w_4$
$w_2 f_{nn} w_1$	$w_2 f_{nn} w_2$	$w_2 f_{nn} w_3$	$w_2 f_{nn} w_4$
$w_3 f_{nn} w_1$	$w_3 f_{nn} w_2$	$w_3 f_{nn} w_3$	$w_3 f_{nn} w_4$
$w_4 f_{nn} w_1$	$w_4 f_{nn} w_2$	$w_4 f_{nn} w_3$	$w_4 f_{nn} w_4$

Disaggregation Matrix – One Industry into Four

As above, I use this disaggregation matrix (S) to create a new flow matrix, F, where F = SfS'. I then aggregate all of the w_2 columns and rows into an RE Production and Sales column and row, and do the same for w_3 (Energy Services) and w_4 (Green Building). I aggregate the remaining w_1 columns and rows into the 'remaining' industry, which is the original BEA industry without the REEE elements.

Once I have re-aggregated the values into the new flow table, I obtain a 68x68 matrix. I then once again divide each cell's value by its industry's total output to arrive at the A matrix (A = F/X where X is total industry output). Then from the A matrix I derive the Leontief inverse matrix as above, then once again form the diagonal matrix 'e' with employment/output values. This time the diagonal matrix will be 68x68, with the first 65 diagonal elements being the BEA employment/output ratios, and the last three diagonal elements being the employment/output ratios I calculated from the survey responses. I then create the 68x68 employment requirements table as follows:

$$E = e(I\text{-}A)^{-1}$$

Where $(I\text{-}A)^{-1}$ is the Leontief inverse table (or total requirements table) and e is the 68x68 matrix with employment/output values along with diagonal and zeros elsewhere.

I now have created a 66x66 input-output table with a single REEE industry and a 68x68 input-output table with three distinct new industries. In the next section I will discuss the results of this analysis.

CHAPTER 6

RESULTS AND DISCUSSION

Results

In this section, I present the present the results from these alternative methods of using the input-output model to analyze the employment effects of expanding the REEE industry. First I present the results from integrating the survey data. I start by integrating the survey responses as a single REEE industry, and then as three separate REEE industries. I present each of these sets of results in turn. Next, I use the synthetic industry approach to model the REEE industry using various specifications. Finally, I use data from the survey to construct weights for synthetic REEE industries so that I can more directly compare these two methods of modeling. I also perform robustness tests for each of these methods of analysis.

Survey Integration Results

REEE Industry

I start by consolidating all of my survey results into a single REEE industry and then integrating this industry into the existing 65x65 BEA input-output tables as described above. Since the existing 65 industries within the BEA tables are disaggregated and re-organized into this new expanded table, all of the employment multipliers from the resulting employment requirements matrix will be slightly different. I present here the employment multipliers (FTE employment per $1 million demand) from the original BEA table as well as the expanded table. As we see in table 11, the original 65 industries see a very slight change in the value of their multiplier, and the 66th industry, REEE, is now explicitly identified.

As shown in table 11, the average total employment multiplier in the original BEA table is 9.28 jobs per $1 million demand, while the average in the expanded table is 9.13. This difference stems almost entirely from changes in the indirect effects, which average 3.50 in the original table and 3.37 in the expanded table. The employment multipliers in industries which are part of the new REEE industry, such as farms (for biomass) and electrical goods (wind, solar, and others), tend to see greater change in their employment multiplier than industries such as social assistance or accommodation, which nevertheless see a change but a much smaller one.

Also in table 11, we see that the REEE industry has an employment multiplier of 7.29 jobs per $1 million, of which 5.24 are the direct jobs and 2.06 are the indirect jobs. These multipliers are below the average on all levels – direct, indirect, and total. The lower direct multiplier indicates that REEE is more capital-intensive than the average industry. The lower indirect multiplier indicates either that the REEE industry has a less significant supply chain than the average industry (there are fewer inter-industry transactions) or that the industries with which REEE transacts also tend to be more capital-intensive (or both factors may come into play). The result is a lower-than-average total multiplier. The results are also lower than the median values, which are 8.60 in the original table and 8.34 in the expanded table.

The REEE industry multiplier of 7.29 compares with industries such as electrical equipment (7.41), primary metal manufacturing (7.08), management of companies (6.98), and publishing industries (7.52). The lowest employment multipliers are found in oil and gas extraction (2.18) and utilities (2.79), while the highest are found in social assistance (20.9) and food services and drinking places (19.08). Below in the discussion section we will evaluate possible reasons why the REEE multiplier is lower than average.

Three Distinct REEE Industries

Next I group the survey responses into three separate categories: RE Production and Sales; Energy Services; and Green Building (which also includes retrofitting). As we observed with the above integration, we will once again see the values of the original employment multipliers change slightly in the expanded tables, with greater change in those industries that are more heavily implicated in the REEE industries. The difference in employment multipliers between the two expanded tables is, however, negligible. In table 12 I present employment multipliers for the original and both expanded tables, where the expanded tables are 66x66 and 68x68. For the sake of clarity, I only present the total multipliers in table 12.

We see from table 12 above that an interesting result emerges. The employment multipliers for RE Production & Sales and for Energy Services are 6.96 and 6.73, respectively. Both of these are lower than the average total multiplier of 9.09. However the Green Building industry has a higher-than-average multiplier of 10.17. This latter multiplier compares with industries such as construction (10.58) and Federal government enterprises (also 10.58). Below I will turn to reasons for the differences between various

REEE multipliers. But first I examine the results of using the synthetic industry approach to measure REEE employment impacts.

Synthetic Industry Results

As previously discussed, the synthetic industry approach consists of determining the components of an industry which is not part of the existing I-O tables, assigning weights to those components, and then forming a vector of change in final demand. This vector of change in demand is then multiplied by the employment requirements matrix to estimate the employment impacts. Using this methodology, I have estimated various specifications for the REEE industry as a whole, as well as components of that industry such as wind, solar, and biomass.

Before turning to the results, I present the weights and components of these various industries and specifications. For these estimates I use the 2006 65-industry BEA input-output tables, which I have converted into an employment requirements matrix. The employment multipliers from this table are presented in the previous section in table 11.

Industries and Weights

The "Green Program" is a composition of various renewable energy and energy efficiency industries as described by Pollin, Heintz and Garrett-Peltier (2009). The renewable energy industries include wind, solar, and biomass, while the energy efficiency industries include building weatherization, mass transit and freight rail, and smart grid development. My co-authors and I first assign weights to each component industry and then aggregate these industries into the "Green Program" which is a weighted average of these six REEE areas. The resulting industries and weights for the Green Program, as well as the industries that comprise it, are in table 13.[36]

Using the industries and weights in table 13, I constructed vectors of change in final demand and pre-multiplied them by the 65x65 employment requirements matrix, as described in the methodology section above. As a result, I obtained employment multipliers (direct and indirect) for the REEE industries listed in table 13. The employment multipliers are shown in table 14.

As we see from the results in table 14, the synthetic industry approach produces results that range from 8.79 (Smart Grid) to 12.83 (mass transportation and freight rail) for total employment multipliers. The Green Program is a weighted average of the six other industries in the table, and this is the industry with which we can most directly compare the employment estimates we found using the integrated survey data approach. Here the Green Program results in an employment multiplier of 10.59 direct plus indirect jobs per $1 million demand. This is higher than my integrated survey result of 7.29. I will discuss reasons for this difference below. Before that, however, I present the results of one other method of estimation.

Using Synthetic Industry Approach with Survey Data

My first set of estimates involved integrating survey data into the I-O tables and creating new industries. The second set of estimates used the existing I-O tables, without

[36] Note that the weights presented here are slightly different from the weights presented in Pollin, Heintz, and Garrett-Peltier (2009). The weights used in that paper were based on a more detailed 440-industry breakdown while here we are analyzing the more aggregated tables at the 65-industry level.

reorganization, to estimate the effects of a demand stimulus using the synthetic industry approach. In this final round of estimation, I create a hybrid of the previous two methods. Here, I use sales data from the firms in our REEE survey to form a vector of final demand, and apply that to the existing (65x65) employment requirements matrix. The REEE sales data serves as my proxy for final demand for REEE products and services. That is, here I form a synthetic industry where the industries and weights derive from my survey data. First I present the weights and then I turn to the resulting employment estimates. Once again, in this table I suppress the industries which have zero values in all categories.

Using the industries and weights in table 15, I generate final demand vectors and apply them to the existing (unmodified 65x65) employment requirements table. This results in the employment estimates shown in table 16.

Interestingly, when I use this approach the order of the size of employment multipliers changes from when I use the integrated survey data. Here, Energy Services now has the highest multiplier, with 10.09 total jobs per $1 million, followed by Green Building at 9.15 and RE Production and Sales with 8.81. With the integrated approach, Green Building had the highest multiplier (10.17) followed by RE Production and Sales (6.96) and finally Energy Services (6.73). Thus the values with the hybrid approach are not only higher in all categories, but also affect the ordering of the industries in terms of the size of the multiplier. My REEE category has a total multiplier of 9.72 using this hybrid approach compared to 6.56 using the integrated approach. We can compare this to the Green Program in the synthetic industry approach, which has a total multiplier of 10.59. Thus the hybrid approach yields a result between the values obtained using the other two approaches. Before turning to a discussion of these various sets of results, I first perform a series of robust tests.

Robustness Tests

Survey Integration Robustness Tests

The input-output model is a snapshot of the economy at a point in time. It does not consist of a distribution or expected values, outcomes that we might test through typical robustness checks such as standard deviations or other tests of statistical dispersion. In order to check the robustness of the results of our survey data integration, therefore, I can perform simple tests throughout the process to ensure that I have correctly manipulated the matrices, and I can compare my results to other methods of estimating employment, as well as to estimates from the original I-O tables, to check whether my results are reasonable.

When integrating the survey data, I start with the original flow table from the BEA, which is a 65x65 table that shows flows (in dollars) of goods and services between industries. I can add the total dollar value of all of the cells in the matrix and use this as a check. When I integrate the survey data, I disaggregate, reorganize, and re-aggregate the original flow table (f) into a new expanded flow table (F). Because this exercise is simply a reorganization of the data, and I am not adding or subtracting any transactions from the economy, the elements of f should equal the elements of F, meaning that the total dollar value of all inter-industry transactions should be the same in the original and expanded tables. I performed this check both with the 66x66 flow matrix as well as with the 68x68 matrix, and in both cases the elements added up to the same value as the elements in the original 65x65 flow matrix.

The other check I can perform that could serve as a robustness test is to compare the employment multipliers from the expanded employment requirements matrix to those obtained using the original ER matrix. I presented these results in tables 11 and 12. If the integration of the data and expansion of the tables had been done incorrectly, we would see large discrepancies between the original and expanded table multipliers. However, as shown in those tables, the differences between the multipliers are small, and result mainly from changes in the indirect effects. Thus I can be reasonably confident that the integration was performed correctly and my results are robust.

Synthetic Industry Specification Tests

The synthetic industry approach does not involve expanding the I-O tables but only multiplying the existing employment requirements table by a vector of final demand. Therefore in order to test the robustness of our results I can alter the specification of the final demand vector to see how sensitive the outcome is to the choice of specification. If a small change in specification produces a large change in the employment multiplier, then the estimates are not likely to be robust. However if a significant change in the specification results in minimal change in the multiplier, then I can be assured that the results are robust. In Chapter 3 I performed one such check using the example of the wind industry. Here I will perform a series of specification tests for the Green Program as well as for the REEE industry. The prior was defined by Pollin, Heintz and Garrett-Peltier (2009) while the latter appears here both in the integrated survey approach and the hybrid approach. I will modify the REEE industry as presented in the hybrid approach, which consists of creating a vector of final demand from the sales data from firms in our survey.

In table 17 we see that a large change in the specification of the green program results in a much smaller change in the employment multiplier. In the original specification of the green program, manufacturing industries had a 20.7% share while non-manufacturing (largely construction) made up the other 79.3%. In each alternative specification, I increase or decrease the shares of manufacturing versus non-manufacturing by 10, 20, and 30 percentage points. A 10 percentage point change in shares results in an employment multiplier that is 2.83 percent different from the original (smaller as the share of manufacturing increases, larger as this share decreases). A 20 percentage point change in specification results is a 5.66 percent change in multiplier, and a 30 percentage change results in a multiplier that changes by 8.49 percent. These results show that my estimation results are not very sensitive to the choice of specification, and that the employment multipliers for the Green Program can be considered robust. These results hold because the various industries that makes up the Green Program – both in services and in manufacturing – have employment multiplier values that are not highly varied. If the green program had included industries such as extraction activities (on the low end of the employment multiplier spectrum) or certain services such as social services (on the high end of the spectrum), the results would have been sensitive to the choice of specification. However, all of the industries which comprise the green program have a range of employment multipliers that is relatively compressed, and therefore even a large change in how these industries are weighted in the overall composition of the program results in only a small change in the green program employment multiplier.

I perform the same exercise with our specification of the REEE industry. Here the original weights are derived from the sales data of firms in our survey, as presented in Table 18. Surprisingly, even though the composition of the individual industries differs between the Green Program and the REEE industry (a point to which I will return below), the shares of manufacturing and non-manufacturing industries are quite similar between the Green Program and the REEE industry, with manufacturing accounting for 20.7 percent of the original specification of the Green Program and 21.6 percent in the original REEE specification.

As in the previous exercise, I find that here the total employment multiplier is not sensitive to the choice of specification. A ten percentage point change in the share of manufacturing versus non-manufacturing results in only a 1.57 percent change in the multiplier. A change as large as 30 percentage points, so that manufacturing makes up a 51.6 percent share instead of the original 21.6 percent, results in an employment multiplier that is only 4.72 percent different from the original (9.26 instead of 9.72). Once again, this result obtains because the various manufacturing and services industries that make up the REEE have a relatively compressed range of employment multiplier values, and do not include some of the more extreme employment multiplier values found in industries such as extraction (extremely low) or social services (extremely high). Therefore a large change in the composition of the industries comprising the REEE industry results in only a small change to the employment multiplier. Thus here as well I can consider my results robust as they are not sensitive to the choice of specification.

Now that I have shown the robustness of my results both using the integrated method and the synthetic industry approach, I turn to a discussion of the results of my analyses.

<u>Discussion</u>

Comparison of Results from Alternative Methods

In the previous sections I presented results for employment impact analysis of the REEE industry by first integrating survey data, then creating synthetic industries, and finally using a hybrid strategy that incorporates data from the first with the methodology of the second. In table 19 I present a comparison of these various results so that I may then discuss my findings and possible sources for variation in the outcomes. I include the REEE industry from the expanded 66x66 I-O method, the three industries from the 68x68 expanded matrix, two industries using the synthetic approach (the Green Program, which we can compare to REEE; and Building Weatherization, which we can compare to Green Building), and well as the REEE industry and 3 sub-components using the hybrid approach.

As we see from table 19, various methods and definitions for estimating employment impacts for the REEE industry lead to a range of results, with a low of 6.73 in Energy Services using the integrated survey approach, and a high of 10.69 in Building Weatherization using the synthetic industry approach. The three overall REEE categories with similar definitions are REEE (66x66), Green Program (Synthetic), and REEE (Hybrid). These have total multipliers of 7.29, 10.59, and 9.72, respectively. The other category that is similar across methods is Green Building. The survey method leads to a

Green Building multiplier of 10.17, while Building Weatherization (synthetic) is 10.69 and Green Building (hybrid) is 9.15. Thus the result of the REEE industry is much more sensitive to the choice of method of analysis, while Green Building is relatively stable across these three methods. This is an expected outcome, since Green Building mainly consists of the construction industry, while REEE is composed of many different industries, each with its own set of multipliers. Below I discuss reasons for differences in these employment estimates. Before doing so, however, I compare my estimates to those published in other studies.

Comparing Results to Other Studies

Here I compare my results to those obtained in previous research, namely the studies I reviewed in Chapter 2. I limit my comparison to studies which used input-output models and developed employment multipliers. In table 20 I compile the results of some of these studies.

From table 20, we see that the three methods of estimation employed here yield results that fall within the range of results found in other studies. Sterzinger (2006) and Singh and Fehrs (2001) present only direct effects for renewable technologies, and thus their estimates fall at the bottom end of the range (5.3 jobs/$1 million and 5.7 jobs/$1 million, respectively). These estimates are followed by studies that report both direct and indirect employment. In that category, Bezdek (2009) estimates 8.6 jobs/$1 million for both energy efficiency and renewables. Estimates by Laitner (2009) of 15.9 jobs/$1 million also include both direct and indirect jobs, but are restricted to energy efficiency. The top end of the range is 26.8 jobs per $1 million, estimated by Roland-Holst (2008).

This estimate captures direct, indirect, and induced effects, but is restricted to energy efficiency. My own estimates include both direct and indirect effects, and both renewable energy and energy efficiency. In comparison to the results in these other studies, my estimates are higher than those which include only direct effects, and lower than those which include only efficiency but not renewable energy.

Turning to estimates that capture both RE and EE, we see that Pollin et al. estimate 16.7 jobs per $1 million in REEE, including direct, indirect, and induced effects. This is not immediately comparable with my results here, however, since I have not modeled induced effects. However, the induced effect modeled by Pollin et al is 40% of the direct plus indirect effects, therefore I can calculate that their direct plus indirect effects (without induced) would be 11.93 jobs per $1 million demand. This study, along with Bezdek (2009), are the only studies which incorporate both renewables and energy efficiency, and that estimate direct plus indirect effects. The estimate in Bezdek (2009) is 8.61 jobs per $1 million of investments in REEE. This falls right in the middle of our own estimates, while the direct plus indirect effects from Pollin et al (2009) are only slightly larger than the estimates developed in this dissertation. Thus I am confident that my methodology and results are both internally and externally robust.

Reasons for Differences between Methods

All of the employment estimates presented here are derived from an input-output model using an employment requirements matrix. Aside from differences resulting strictly from the inherent methodological differences (discussed below), any other difference in the estimates can be traced to three sources: output multipliers (which show the effects of industry output and inter-industry transactions), employment/output ratios (which convert inter-industry transactions into an employment requirements matrix), and differences in final demand. The differences in output multipliers and employment/output (E/O) ratios apply to all three strategies. The differences in final demand are relevant only for the synthetic and hybrid approaches, since these rely on changing the vector of final demand. I discuss each of these sources of variation in turn, and end the discussion with the differences due strictly to methodology.

Differences in Output and Employment Multipliers

Within any input-output model, each industry will have its own unique set of interactions with other industries the economy, its own production function. Some industries will buy inputs from many others, while other industries will buy few. Likewise, the output that a given industry produces may be used by itself, by other industries, or by various sources of final demand, and each industry will have its own unique set of output (and sales) relationships. The Leontief Inverse matrix captures the inter-industry transactions and allows us to calculate output multipliers for each industry. An output multiplier shows how many dollars of total output are produced economy-wide in order to satisfy one dollar of demand for an industry's product. If we take the example of the farming industry, in order to satisfy a consumer's demand for $1 of output (say, wheat), the farm industry must produce $1 worth of wheat, plus some of its own products that go into producing wheat (such as seed) and must use the output of other industries (such as farm equipment from the machinery industry and fertilizer from the chemical industry). Therefore $1 in final demand creates more than $1 of total output. The Leontief Inverse matrix shows how much output, by industry, is generated by the additional demand. By comparing output multipliers, we can see the extent to which industries rely more or less heavily on the output of other industries, thus how much additional economic activity is generated by increased demand for each industry's products. The output multipliers for the three versions of my Leontief Inverse matrix (65-, 66-, and 68-industry) are presented in table 21.

Continuing with the example above, we see that for the farm industry, in order to meet $1 of final demand, there are about $2.36 of output economy-wide, including $1.20 in the farm industry itself and about $1.17 in other industries which supply it. Turning now to REEE, we see that in the 66-industry expanded table, $1.47 of output is produced economy-wide for every $1 demand for REEE goods and services. We see that most of this increased output comes from industries which supply REEE, rather than the REEE industry using its own output as inputs. The output multiplier of 1.47 is lower than the average multiplier across all industries of 1.93. Since the output multiplier table isolates input-output relationships before we introduce employment, this result shows that the lower-than-average employment multipliers (previously discussed) stem at least in part from lower-than-average input-output relationships. When we decompose the REEE into three distinct industries and create a 68x68 table, the direct output multiplier for these industries is once again close to one, below the average direct multiplier of 1.10. Here, however, we see that RE Production & Sales and Green Building have higher-than-average indirect multipliers, resulting in total output multipliers that are very close to the average across all industries. Energy Services has lower indirect and total output multipliers, and as a result falls below the industry average. Thus this sub-component of the REEE industry may be driving the lower-than-average output multiplier of the REEE industry in the 66-industry table. Therefore the low employment multipliers for REEE as a whole as well as for Energy Services in particular are driven at least in part by input-output relationships. RE Production & Sales, however, has a lower-than-average employment multiplier but an average output multiplier, therefore the low employment multiplier must be attributable to another cause, namely, a low employment/output ratio.

<u>Differences in Employment/Output Ratios</u>

The ratio of employment to output is a measure of labor intensity. It is a ratio of the number of full-time-equivalent jobs per $1 million in gross output for each industry in the matrix. Lower E/O ratios imply lower labor intensity, and vice versa. As described earlier, the E/O ratio for each industry is multiplied through the Leontief inverse matrix in order to create an employment requirements matrix. If two industries have similar output multipliers but different employment multipliers, then this difference is attributable to differences in E/O ratios.

As an example, the RE Production & Sales industry has an output multiplier that is close to the average, but an employment multiplier that is below average. We know, therefore, that this discrepancy stems from a low E/O ratio, implying that RE Production & Sales is less labor-intensive than the average industry. Below I compare the total output multipliers, employment multipliers, and employment/output ratios for each of our REEE categories as well as the industry averages. Note that the employment multiplier is *not* the product of the output multiplier and the E/O ratio. The employment multiplier accounts for the E/O ratios in all of the industries supplying inputs to and buying output from the industry in question.

We see from table 22 that REEE, RE Production & Sales, and Energy Services all have lower-than average employment multipliers. This table shows that the source of the lower multiplier is different in all three cases. In the case of the combined REEE industry, both a lower output multiplier and a lower E/O ratio contribute to the lower employment multiplier. In RE Production & Sales, the lower employment multiplier is entirely attributable to a lower E/O ratio, and in Energy Services it is entirely attributable to a lower output multiplier. Green Building stands alone, in that it has a higher-than-average employment multiplier, which we see here is the result of a higher-than-average E/O ratio. These results indicate that REEE and RE Production & Sales are more capital-intensive than the average industry while Green Building is more labor-intensive. Energy Services has average labor intensity but has a lower level of inter-industry transactions.

The E/O ratios, which are presented above and used in my integrated I-O analysis, derive from data collected by firms in our survey, which is only a small sample of all of the firms in the REEE industry. It is quite possible that the firms in our survey are not representative of the entire population of REEE firms, and that the E/O ratios based on our survey respondents are lower than the true population value of the economy-wide REEE E/O ratio. If indeed the true E/O ratio is higher, then of course the employment multiplier would itself also be higher. In three of the four cases presented above, the E/O ratio is a driver in the employment multipliers being above or below the mean. Below, I present the results of a counterfactual test: What if the E/O ratio was the same as the industry average? I re-create the employment requirements matrix for the 66- and 68-industry tables and present the outcomes in table 23.

As we see from table 23, when I use the average E/O ratios to create the employment requirements matrix, the employment multipliers for REEE and RE Production & Sales both rise, while those for Energy Services and Green Building both fall. This is of course the anticipated result, since the prior two categories had lower-than-average E/O ratios and the latter had higher-than average. The resulting differences in employment multipliers between each of these industries and the industry average are then attributable to differences in inter-industry transactions, which are captured by the output multipliers. RE Production & Sales now has an average-level employment multiplier, and Green Building remains above-average. REEE as a whole, however, as well as its component industry Energy Services, both still have below-average employment multipliers which are therefore attributable to below-average inter-industry transactions.

In order to compare the results across different methods of analysis, I can conduct a similar exercise to decompose the synthetic industry multipliers into output multipliers and E/O ratios, and compare those with the above results which use the integrated survey data. The synthetic industry approach uses a demand stimulus to estimate employment effects. I use the same composition and weights to form a weighted average E/O ratio for each of the synthetic industries. In table 24 I present the results for the Green Program and for Building Weatherization, the two synthetic industries most directly comparable with the REEE results presented above.

Table 24 shows that the Green Program (synthetic) has an above-average output multiplier and E/O ratio, resulting in an above-average employment multiplier. We contrast this with the REEE industry (integrated) which has below-average values in both of these areas. Thus REEE as modeled has a lower employment multiplier than the Green Program due to both lower inter-industry transactions and lower labor intensity.

Building weatherization in the synthetic approach also has a higher-than-average output multiplier and E/O ratio, and is higher than the integrated Green Building industry in both categories. The slight difference between the total employment multipliers in Building Weatherization and Green Building is therefore also attributable to variations in both inter-industry transactions and labor intensity, though the differences in both of these categories are relatively small.

Differences in Final Demand

The employment estimates may vary between different specifications for the REEE industry for an additional reason, which is differences in the composition of final demand. This applies mainly to the synthetic and hybrid approaches, which multiply a vector of change in final demand to the current employment requirements matrix to estimate employment impacts of expanding the REEE industry. The hybrid approach, however, can also shed light on the results from the integrated approach. The two sources of variation in the integrated approach are the E/O ratio and the output multipliers, which show the extent of inter-industry transactions. If we look at sales by the REEE firms in our survey, this gives a partial indication of inter-industry transactions (outputs, not inputs). It is this sales vector that I use in the hybrid approach. Thus if we compare the survey sales vector to the vector of demand used for the Green Program or Building Weatherization, we will see differences in industrial composition that will allow us further to isolate the source of the variation. In tables 13 and 15, I show the composition of synthetic industries and the survey demand stimulus, respectively. In table 25 I present the Green Program and REEE Industry from those tables, and highlight the industries in which the share of demand varies by more than five percentage points between the Green Program and REEE. I suppress the rows that have zero values for both REEE industries.

As we see from table 25, there are a few significant differences in the industrial composition of the REEE survey sales as compared to the Green Program. The three biggest differences are found in Construction; Miscellaneous professional, scientific, and technical services; and Waste management. In the case of construction, the Green Program weights this category much more heavily – it accounts for just over half of all Green Program industrial activity. In the case of the professional/scientific/technical services and waste management, these are represented much more heavily in the survey responses than in the synthetic Green Program. Other notable categories that have a more significant presence in the survey sample are non-metallic mineral products, miscellaneous manufacturing, and education, while transit and ground passenger transportation make up a greater share of the Green Program demand. These differences are all greater than five percentage points, and may have a significant impact in determining the value of output multipliers for these industries, which, as we see above, differ from each other. My survey may have over-sampled advocacy and education groups, or perhaps the Green Program should explicitly include this industry in its composition. Likewise, in all of these categories where significant differences are present, it may be the case that the survey sample is not representative, or it could be that the Green Program is not properly specified. The above information does not tell us which is the case. It does, however, offer some guidance as to how I might redefine the synthetic industries or improve the sampling and survey responses in future surveys.

Inherent Methodological Differences

As discussed in chapter three, the synthetic industry approach and integrated industry approach differ in one major way – the synthetic approach treats changes in demand for REEE products and services as an exogenous shock, while the integrated approach endogenizes this industry and therefore captures linkages in both directions. This difference may be an important factor driving the differences in results between the synthetic and integrated approaches. In the synthetic approach, the REEE industry ("Green Program") is treated as a consumer with a unique set of final demands (metal, hardware, turbines, and so on). In the integrated approach, the REEE industry consumes inputs from other industries but also enters into the production function of other industries as it supplies output to meet intermediate demands.

If, however, the REEE industry is an insignificant provider of goods and services to other industries (in other words, if REEE serves mainly final demands but not intermediate demands), then the results from the two approaches could be quite similar, or the multipliers from the integrated approach could even be lower than those of the synthetic approach. For example, if REEE is small relative to other industries, then the level of inter-industry demand for REEE may be minimal in relation to demand for the output of other industries. Another possibility is that REEE products are treated as capital improvements or investment goods, and are not part of the 'flow' of goods and services that is captured within the basic I-O framework.[37] If this is the case, the REEE industry may indeed function more as a consumer, as it buys inputs from multiple industries but does not itself enter into the production function of those (or other) industries. It is quite possible that one or both of these factors – the size of the industry and the treatment of its products as capital – could explain the low level of inter-industry transactions in the integrated approach, as captured by the below-average output multiplier discussed above. This lower output multiplier drives the lower employment multiplier. This lower level of inter-industry transactions would manifest itself only in the integrated approach, and not the synthetic industry approach, and therefore this could be an important factor in explaining the lower REEE employment effects obtained with the integrated approach.

Which Estimation Method Is More Accurate or Appropriate?

As we see from the results above, there are some non-negligible differences in modeling REEE employment depending on which method of analysis we use. Which method is more accurate or appropriate? It is not immediately clear that one approach is superior to the other. The integrated survey method is an analytically sound approach, but is potentially fraught with errors due to the size, scope, and reliability of our survey responses. The sample of REEE firms, though nationwide and representing various parts

[37] Dynamic input-output models introduce both a time dimension and investments in capital stock. These models build upon the static model used here by introducing a separate capital coefficients matrix in which each entry represents the stock of capital of industry *i* which is used by industry *j* over time period *t*. For more on this issue, see (Richardson, 1972) or (Leontief, 1986).

of the REEE industry, may in fact be unrepresentative of the true population of REEE firms. Our survey responses may over-represent some industries and under-represent others. There may also be reporting errors by the respondents that lower the quality of the data. We may have captured too many small firms or newer firms, since the industry is growing rapidly and since some larger firms were unwilling to report their financial data. Finally, the survey results were adjusted for inflation, growth, and scale before being integrated and there may be discrepancies resulting from these adjustments. The synthetic industry approach may therefore be more accurate or reliable, since it involves using data in the existing BEA input-output tables, which are created from surveys of millions of firms and are therefore much more representative of the population of U.S. businesses.

The integrated survey approach is, however, superior to the synthetic industry approach in some ways. The synthetic approach uses only a demand stimulus, capturing one side of the effects of the REEE industry. The integrated approach captures not only the sales (output) of the REEE firms but also integrates data on their inputs, thus generating a more complete picture of the economic impacts and inter-industry transactions of which REEE plays a part.

The hybrid approach, finally, is essentially just a different and potentially better way to compose the final demand vector, but suffers from the same problem of not capturing intermediate demand of the REEE industry. Since it is based on survey data, it could also suffer from the problems noted above that are inherent to smaller-scale surveys.

Thus all of these approaches offer insights into modeling employment in the REEE, but none is superior in all ways to others. The ideal, of course, would be that the U.S. Department of Commerce creates NAICS codes for the REEE sector, and that the Census Bureau collects and identifies this sector as part of their Economic Census and other business surveys. Until then, we can use one or more of the approaches presented here to estimate the employment impacts of investment in renewable energy and energy efficiency.

Policy Implications of Alternative Approaches

One major objective of estimating employment effects of various energy investments is to contribute to the public debate and policy discussions on this topic. Government policy can support the expansion of REEE through a variety of mechanisms, including tax credits and rebates, standards or mandates, direct public procurement, education and advocacy programs, and so forth. In order to make informed decisions about whether or not to support clean energy programs, policy makers will consider both the environmental and economic effects of energy policy, as well as the specific impacts on their own constituency. Employment is of particular concern to policy makers (as noted by Berck and Hoffman (2002)) and therefore a comprehensive assessment of employment impacts, which considers both the job losses as well as job gains of REEE investments, is of critical importance to political decision-makers.

Above I presented the results of various methods for analyzing REEE investments. I estimated employment multipliers in the REEE industry using the integrated approach and in the Green Program using the synthetic industry approach. To be relevant for policy applications, we must also consider the employment multipliers in fossil fuels, the industries that will lose jobs as we transition to a more energy-efficient system with a greater share of power produced by renewable energy.

In table 26 I show employment multipliers for various fossil fuel and REEE industries based on my two primary methods of analysis. This table shows that by any specification and method of estimating the REEE industry, the employment multiplier is greater than in any fossil fuel industry, implying that a dollar per dollar shift from fossil fuel spending to REEE spending will create a net positive number of jobs. The direct employment effects for the three REEE specifications range from a low of 5.24 to a high of 6.40, whereas the greatest direct effect in fossil fuels is found in mining (such as for coal), with a direct effect of 3.24. The total (direct plus indirect) effects in REEE range from 7.29 to 10.59, whereas in fossil fuels the range of total effects is from 2.26 to 5.74. Thus even the most labor-intensive fossil fuel industry (support activities for mining) still creates fewer jobs per dollar than the least labor-intensive specification of REEE. Thus an economy-wide shift to renewable energy and energy efficiency will create more jobs than it destroys.

CHAPTER 7

CONCLUSION

Chapter Summary

In this dissertation I first presented background statistics on energy use and emissions within the U.S., and situated my work within the broader context of climate change policy. We saw that the U.S. currently relies mainly on fossil fuels as an energy source, while renewables make up less than eight percent of total energy consumption. Energy intensity is declining at a rate of only two percent per year while GDP is rising at a faster rate, resulting in projected increases in energy demands, including increases in fossil fuel consumption which will contribute to rising carbon emissions. Under a business-as-usual scenario, renewable energy and energy efficiency will grow only slightly over the next few decades, far too slowly to be an effective response to climate change pressures. However, even with currently available technologies, many opportunities exist to increase our energy efficiency as well as our use of renewables. Together, REEE can contribute nearly half of the carbon emissions reductions needed to meet necessary abatement levels. The other half can be achieved through behavioral change which conserves energy, through strategies such as reforestation or otherwise increasing carbon sinks, and according to some scenarios, through the use of carbon capture and sequestration as well as nuclear power.

In chapter two I reviewed the studies of the economic impacts of REEE investments. While these investments are necessary to meet climate policy goals, it is also vital to understand the economic and especially the employment impacts. The studies I reviewed in chapter two take a variety of approaches to address this question. Many are based on an input-output framework while others use non-modeling techniques such as case studies. Within the modeled approaches, I find that the input-output model is used in two ways. Some, such as Pollin and Garrett-Peltier (2009), use the I-O model to estimate the number of jobs created by a given level of REEE investment. Others, such as Laitner (2009), concentrate on the effects of energy efficiency investments, estimate the cost savings that can be achieved through EE, then use the I-O model to estimate the jobs that result from these cost savings. Finally, other researchers such as Singh and Fehrs (2001) conduct interviews to estimate the number of jobs per level of energy output (jobs/MW) at certain renewable energy manufacturing firms. The studies presented in chapter two represent a range of methodologies, yet they come to a central conclusion, which is that investments in renewable energy and/or energy efficiency will have positive impacts on employment, even after considering job losses in fossil fuels.

In chapter three I describe the input-output model in detail and discuss the current limitations of using the I-O model to study REEE, an industry which is not identified in the I-O tables. Researchers have attempted to overcome this limitation in a number of ways. Pollin and Garrett-Peltier use a ‘synthetic industry’ approach which consists of identifying the components of REEE technologies (both manufactured goods and services), assigning weights (cost shares) to those components and then creating a vector of final demand. We can then apply this vector to the existing I-O tables and simulate the effects of increased demand for REEE goods and services. I perform this same analysis here, and also present a method which can be used to test for the robustness of the results.

The I-O model can be expanded to include the REEE industry if we have sufficient data on REEE firms. I undertake a survey to collect such data and present my survey methods and results in chapter four. I compiled a sample of 1,000 firms nationwide, sent nearly 500 questionnaires to firms, and received just over 100 complete and useable responses. These responses came from a variety of REEE businesses, including wind and solar technology manufacture and distribution, construction and design companies engaged in green building, and a variety of energy service companies such as energy auditors and education organizations.

In chapter five I present the methodology for integrating this data into the I-O tables. The methodology was developed by other authors, but to my knowledge no one has yet applied it to the renewable energy and energy efficiency industry. I perform two levels of integration. First, I integrate the full set of survey results into one REEE industry. And secondly I divide the survey results into three groups and separately integrate industries which I call “RE Production and Sales,” “Energy Services,” and “Green Building.” The methodology is quite similar for these two integration exercises, and I test my analysis and results for accuracy.

I present the results of these alternative methods in chapter six, which also contains a discussion of the results, robustness tests, and comparison of the results to previously published estimates. I find that REEE generates between 6.56 and 10.59 jobs (direct plus indirect) per $1 million investment depending on the method of analysis. The low end is the result of the survey integration method and the high end is the result of the synthetic industry approach. I decompose these results into differences in output multipliers (inter-industry relationships), employment/output ratios (labor intensity), and composition of final demand. I find that all three of these factors will affect the value of the employment multiplier, and I discuss reasons for the discrepancies. I determine that neither approach is superior in all capacities to the other. The survey approach has the advantage of using actual data but could suffer from an unrepresentative sample or reporting errors. The synthetic industry approach has the disadvantage of only considering the output relationships (not inputs) and using industry averages which might not always be a good proxy for REEE firms, however it has the advantage of being based on actual data from a much larger number of firms than our survey.

Contributions of this Dissertation

This dissertation has contributed to the literature on the employment impacts of renewable energy and energy efficiency in a number of ways. First, I have provided a review of various studies and methods used to address this question. Since this literature is growing so rapidly, a review of this type has not heretofore been completed, and this dissertation will advance our understanding of the advantages, drawbacks, and comparability of using alternative modeled and non-modeled approaches.

More importantly, in this dissertation I expand upon current methods of using input-output analysis to address REEE employment. Due to data limitations, researchers have until now been constrained in their ability to use the I-O model to study the REEE industry, and the authors that collect primary data to analyze REEE employment generally have very small samples and present only case studies from which we can not necessarily draw macroeconomic implications. Here I overcome this data constraint in two ways.   First I develop the 'synthetic industry' approach used by Pollin, Garrett-

Peltier, and others (Pollin, et al. 2008), (Pollin, Heintz, & Garrett-Peltier, 2009), (Pollin & Garrett-Peltier, 2009). I also present a robustness test that can be used for this approach. Secondly I collect data from REEE firms throughout the U.S. and integrate this data into the input-output accounts. Not only does the new data set contribute to this research area, but to my knowledge, this is the first time this methodology has been used to examine the economy-wide impacts of the REEE industry. The results of these alternative research methods substantiate the results previously obtained by others, namely that investments in renewable energy and energy efficiency will have positive employment impacts, even after accounting for job losses in fossil fuel industries.

Policy Implications

These contributions are politically both timely and relevant. With increasing attention to the impacts of climate change on our environment and our economy, scientists and economists are studying the ramifications of both action and inaction. Studies have shown that energy efficiency and renewable energy can play a significant role in abating carbon emissions. In order to drastically increase our carbon productivity we need both public and private investment in renewable energy and energy efficiency. The public sector can use market and regulatory mechanisms to speed the diffusion of REEE technologies and slow the use of fossil fuels. These mechanisms can take the form of tax credits and rebates for clean energy; public procurement of clean vehicles; energy retrofits to public buildings; building and land-use codes; grants to organizations, municipalities, and states to weatherize buildings and pursue other clean energy strategies; carbon taxes or cap-and-permit systems; and a host of other regulatory and financial incentives to encourage individuals and businesses to reduce their use of carbon, increase their use of renewable energy, and become more energy efficient.

Many opportunities and technologies already exist for us to transition to a cleaner energy economy. The research presented in this dissertation confirms the findings that a clean energy transition will also contribute to the growth of employment. Renewable energy and energy efficiency are more labor-intensive than carbon-based fuels, and thus it is reasonable to assume that a transition from fossil fuels to REEE will have positive employment impacts. This dissertation confirms this to be true, and through the use of an input-output model as well as primary data collected from REEE firms across the U.S. we see that the economy-wide impacts of employment from REEE investments are positive. The magnitude of the effect depends on the type of model we use – the effects are greater through the synthetic industry approach than the integrated survey data approach – but in either case the outcome is the same: A transition from carbon-based energy to REEE will be a net source of job creation.

Directions for Further Research

In this dissertation, I use a static input-output model and conduct comparative static exercises to estimate employment effects. While this is an appropriate estimation method in the short-run, it is not appropriate for long-run analysis of a transition to renewable energy and efficiency. In order to study long-run effects, I would need to incorporate both a time dimension and a capital coefficients matrix into the input-output model. It would also be important to adjust production functions over the longer term, as firms change their inputs of energy goods, capital, and labor in response to changes in energy availability or price. Including a time dimension and capital coefficients would create a dynamic input-output model, whereas building in additional equations and assumptions about factor substitution and other changes in consumption and production functions would lead to the building of a CGE model. Despite the shortcomings of CGE models (due mainly to their multiple assumptions and lack of transparency), this may be the most appropriate method for studying the long-run effects of REEE investments.

Another important dimension to include in future analysis is the geographical distribution of job losses and gains resulting from a decline in fossil fuel production and an increase in REEE. I only briefly discussed the net employment effects in chapter six – that is, the employment gains from REEE in comparison to the loss in fossil fuel jobs. However, in this dissertation I have only analyzed national data, and the job losses in particular may be concentrated in certain regions of the country that are large coal producers (e.g. Appalachia) or oil producers (e.g. the Gulf Coast). In order to target REEE investments and training programs toward workers who would lose their jobs in fossil-fuel industries, we would need to study the geographical distribution of those jobs.

Finally, we have seen that a shift from fossil fuels to REEE will generate a net increase in employment and a reduction in carbon emissions, and that therefore there is a case to be made for public support of a transition to clean energy. Further research could evaluate the most effective means to speed the transition to REEE, including evaluating market mechanisms such as carbon taxes or renewable energy tax credits, and regulatory mechanisms such as building codes and renewable portfolio standards.

In short, the directions for further research include evaluating the political tools that could best speed the transition to clean energy, analyzing the regional impacts of the job gains and losses resulting from that transition, and expanding our basic input-output model in order to study the long-run effects of a transition to REEE.

Table 1: U.S. Energy Consumption by Energy Source, 2004 - 2008

(Quadrillion Btu)					
Energy Source	**2004**	**2005**	**2006**	**2007**	**2008**
Total	**100.349**	**100.485**	**99.876**	**101.552**	**99.305**
Fossil Fuels	85.830	85.817	84.690	86.174	83.436
Coal	22.466	22.797	22.447	22.748	22.421
Coal Coke Net Imports	0.137	0.045	0.061	0.025	0.040
Natural Gas	22.931	22.583	22.224	23.628	23.838
Petroleum	40.294	40.393	39.958	39.773	37.137
Electricity Net Imports	0.039	0.084	0.063	0.106	0.113
Nuclear Electric Power	8.222	8.160	8.214	8.458	8.455
Renewable Energy	6.260	6.423	6.909	6.814	7.301
Biomass	3.023	3.133	3.361	3.597	3.884
Biofuels	0.513	0.594	0.795	1.025	1.413
Waste	0.389	0.403	0.414	0.430	0.431
Wood Derived Fuels	2.121	2.136	2.152	2.142	2.041
Geothermal Energy	0.341	0.343	0.343	0.349	0.358
Hydroelectric Conventional	2.690	2.703	2.869	2.446	2.453
Solar/PV Energy	0.065	0.066	0.072	0.081	0.091
Wind Energy	0.142	0.178	0.264	0.341	0.514

Source: U.S. Energy Information Administration,
http://www.eia.doe.gov/cneaf/alternate/page/renew_energy_consump/table1.html

Table 2: Renewable Energy Power Generation – Level and Growth, 2007-2035

Energy Source	**Generation (billion kilowatt-hours)**		**Annual Growth (percent)**
	2007	**2035**	**2008-2035**
Conventional Hydropower	245.13	299.45	0.7%
Geothermal	14.64	28.13	2.4%
Biogenic Municipal Waste	13.88	24.95	2.0%
Wood and Other Biomass	10.59	117.45	9.2%
Dedicated Plants	8.65	82.01	8.5%
Co-firing	1.94	35.43	11.4%
Solar Thermal	0.60	2.10	3.6%
Solar Photovoltaic	0.01	1.13	14.2%
Wind	34.45	213.84	5.4%
Offshore Wind	0.00	0.75	--
Total	**319.29**	**687.80**	**2.7%**

Source: Energy Information Administration, Annual Energy Outlook 2010 Early Release Overview

Table 3: Selected Employment Multipliers from BEA Input-Output Tables

Industry	**Direct FTE Jobs per $1 million demand**	**Indirect FTE Jobs Per $1 million demand**	**Total Direct + Indirect FTE Jobs per $1 million demand**
Oil and gas extraction	0.64	1.62	**2.26**
Construction	6.13	4.56	**10.69**
Fabricated metal products	5.53	3.72	**9.25**
Computer and electronic products	4.10	4.17	**8.27**
Administrative and support services	13.80	2.48	**16.28**

Table 4: Specification Test for Synthetic Industry, Using Wind Industry as Example

Specification	**Wind – original**	**Wind – alternative #1**	**Wind – alternative #2**
	Weights		
Construction	26.00%	33.88%	18.12%
Plastics and Rubber Products	12.00%	10.21%	13.79%
Fabricated metal products	12.00%	10.21%	13.79%
Machinery	37.00%	31.48%	42.52%
Computer and electronic products	3.00%	2.55%	3.45%
Electrical equipment, appliances, and components	3.00%	2.55%	3.45%
Miscellaneous professional, scientific and technical services	7.00%	9.12%	4.88%
Total Share of Manufacturing Industries	**67.00%**	**57.00%**	**77.00%**
Total Share of Non-Manufacturing Industries	**33.00%**	**43.00%**	**23.00%**
Employment Impacts (FTE Employment per $1 million demand)			
Direct	4.85	5.02	4.69
Indirect	4.33	4.32	4.34
Total	9.19	9.34	9.03
% +/- original specification		+1.6%	-1.7%

Table 5: Sample Size and Sampling Error for the 95 percent Confidence Interval

	Sample Size for the 95 percent confidence interval		
Population Size	±3% sampling error	±5% sampling error	±10% sampling error
100	92	80	49
250	203	152	70
500	341	217	81
750	441	254	85
1,000	516	278	88
2,500	748	333	93
5,000	880	357	94
10,000	964	**370**	**95**
25,000	1,023	**378**	**96**
50,000	1,045	**381**	**96**
100,000	1,056	**383**	**96**
1,000,000	1,066	**384**	**96**
100,000,000	1,067	**384**	**96**

Source: (Salant & Dillman, 1994)

Table 6: Summary Statistics of Survey Responses

Industry		# of responses	Total Full-Time-Equivalent Employment	Total Sales (domestic plus exports)	Average number of employees per firm	FTE Jobs per $1 million sales
Biomass		12	35.58	10,423,587	3	3.413
Energy Services		29	1056.08	190,582,103	36	5.541
incl.	design/engineering	6				
	consulting/auditing	11				
	marketing/promotion	3				
	education/advocacy	4				
	recycling/conservation	3				
	Other	2				
Green Building		22	123.90	14,366,330	6	8.624
REEE production and sales		15	310.00	102,311,707	21	3.030
Retrofitting		7	153.50	32,478,085	22	4.726
Solar		14	74.25	13,735,470	5	5.406
Wind		2	64.00	26,505,122	32	2.415
Total useable questionnaires		**101**	**1817.30**	**390,402,404**	**18**	**4.655**

Table 7: Survey Responses Grouped into 3 Distinct Categories

Survey Categories	**Complete, useable surveys**
Renewable Energy	43
Energy Services	29
Green Building and Retrofitting	29
Total	101

Table 8: 2005-2007 Growth by REEE Industry Group

Industry Group	2005-2007 annual growth rate
REEE Production and Sales[38]	31%
Solar PV[39]	31%
Wind[40]	26%
Biofuel[41]	31%
Energy Services[42]	22%
Green Building[43]	23%

[38] (Energy Information Administration 2009)

[39] DOE-EERE (33%) (United States Department of Energy, Office of Energy Efficiency and Renewable Energy 2006); and ACORE (29%) (American Council on Renewable Energy 2007)

[40] (United States Department of Energy, Office of Energy Efficiency and Renewable Energy, 2007); (American Council on Renewable Energy 2007)

[41] (Energy Information Administration 2009)

[42] (Hopper 2007)

[43] (Building Design and Construction 2003); (PRNewswire 2007)

Table 9: Employment/Output Ratios for 66-industry Employment Requirements Matrix

Industry	*Employment-Output Ratio (Full-time equivalent employment per $1 million gross output)*
Farm products (unprocessed)	2.537
Forestry, fishing and related	9.600
Oil and gas extraction	0.531
Mining, except oil and gas	2.913
Support activities for mining	2.192
Utilities	1.213
Construction	6.099
Food and beverage and tobacco products	2.436
Textile mills and textile product mills	4.909
Apparel and leather and allied products	8.828
Wood products	5.101
Paper products	2.739
Printing and related support activities	6.394
Petroleum and coal products	0.207
Chemical products	1.336
Plastics and rubber products	3.770
Nonmetallic mineral products	4.020
Primary metals	1.986
Fabricated metal products	4.906
Machinery	3.690
Computer and electronic products	3.343
Electrical equipment, appliances, and components	3.665
Motor vehicles, bodies and trailers, and parts	2.144
Other transportation equipment	3.483
Furniture and related products	6.496
Miscellaneous manufacturing	4.278
Wholesale trade	5.057
Retail trade	10.272
Air transportation	3.159
Rail transportation	2.841
Water transportation	1.654
Truck transportation	5.148
Transit and ground passenger transportation	13.150
Pipeline transportation	1.105
Other transportation and support activities	8.749
Warehousing and storage	12.557
	(continued on next page)

(continued from previous page)	
Publishing industries (includes software)	3.090
Motion picture and sound recording industries	3.350
Broadcasting and telecommunications	1.724
Information and data processing services	2.478
Federal Reserve banks, credit intermediation, and related activities	3.799
Securities, commodity contracts, and investments	1.890
Insurance carriers and related activities	3.598
Funds, trusts, and other financial vehicles	0.890
Real estate	0.667
Rental and leasing services and lessors of intangible assets	2.266
Legal services	4.774
Miscellaneous professional, scientific and technical services	4.769
Computer systems design and related services	6.199
Management of companies and enterprises	4.378
Administrative and support services	12.903
Waste management and remediation services	4.625
Educational services	13.006
Ambulatory health care services	7.205
Hospitals and nursing and residential care facilities	10.440
Social assistance	17.996
Performing arts, spectator sports, museums, and related activities	4.705
Amusements, gambling, and recreation industries	11.818
Accommodation	9.056
Food services and drinking places	15.343
Other services, except government	10.291
Federal government enterprises	7.519
Federal general government	4.092
State and local government enterprises	4.693
State and local general government	9.293
Renewable Energy and Energy Efficiency	5.177

Table 10: Employment/Output Ratios from REEE Survey Data

Survey Industry	**Employment/Output Ratio (FTE Jobs per $1 million sales)**
RE Production and Sales	3.16
Energy Services	5.54
Green Building	5.92
REEE(single industry)	5.18

Table 11: Employment Multipliers in Original and Expanded I-O Tables

	Employment Multipliers (FTE Employment per $1 million demand)					
	Original 65x65 Table			Expanded 66x66 Table		
	Direct	Indirect	Total	Direct	Indirect	Total
Farms	3.03	4.45	**7.48**	2.94	3.57	**6.51**
Forestry, fishing, and related activities	13.98	2.25	**16.23**	13.66	2.13	**15.79**
Oil and gas extraction	0.64	1.62	**2.26**	0.64	1.54	**2.18**
Mining, except oil and gas	3.24	2.35	**5.59**	3.23	2.26	**5.50**
Support activities for mining	2.20	3.53	**5.73**	2.20	3.29	**5.49**
Utilities	1.22	1.68	**2.90**	1.22	1.57	**2.79**
Construction	6.13	4.56	**10.69**	6.13	4.46	**10.58**
Food and beverage and tobacco products	2.89	5.72	**8.60**	2.86	5.29	**8.16**
Textile mills and textile product mills	6.01	4.47	**10.48**	6.06	4.56	**10.62**
Apparel and leather and allied products	9.62	4.26	**13.88**	9.63	4.29	**13.93**
Wood products	6.55	6.50	**13.06**	6.49	6.37	**12.85**
Paper products	3.41	4.62	**8.04**	3.48	4.95	**8.43**
Printing and related support activities	6.63	4.09	**10.72**	6.63	4.12	**10.75**
Petroleum and coal products	0.23	2.82	**3.06**	0.23	2.75	**2.99**
Chemical products	1.80	3.65	**5.44**	1.79	3.55	**5.34**
Plastics and rubber products	4.07	4.54	**8.61**	4.06	4.47	**8.53**
Nonmetallic mineral products	4.50	3.68	**8.18**	4.45	3.65	**8.11**
Primary metals	2.80	3.70	**6.50**	2.91	4.17	**7.08**
Fabricated metal products	5.53	3.72	**9.25**	5.48	3.66	**9.14**
Machinery	4.03	4.57	**8.61**	3.99	4.38	**8.36**
Computer and electronic products	4.10	4.17	**8.27**	4.13	4.23	**8.35**
Electrical equipment, appliances, and components	3.90	3.69	**7.59**	3.86	3.55	**7.41**
Motor vehicles, bodies and trailers, and parts	3.04	5.91	**8.95**	3.05	5.95	**9.00**
Other transportation equipment	3.91	4.08	**7.99**	3.90	3.87	**7.77**
Furniture and related products	6.62	5.20	**11.83**	6.62	5.21	**11.83**
Miscellaneous manufacturing	4.54	4.17	**8.71**	4.51	3.98	**8.48**
Wholesale trade	5.26	2.26	**7.53**	5.26	2.17	**7.43**
Retail trade	10.33	2.53	**12.87**	10.33	2.42	**12.75**
Air transportation	3.17	4.22	**7.39**	3.17	4.60	**7.77**
Rail transportation	2.85	3.25	**6.10**	2.85	3.13	**5.98**
Water transportation	1.65	5.45	**7.10**	1.65	5.92	**7.57**

(continued on next page)

(continued from previous page)						
Truck transportation	5.92	3.62	**9.54**	5.90	3.51	**9.41**
Transit and ground passenger transportation	13.50	2.96	**16.46**	13.48	2.84	**16.32**
Pipeline transportation	1.13	3.74	**4.87**	1.13	3.57	**4.70**
Other transportation and support activities	9.12	1.58	**10.70**	9.11	1.51	**10.62**
Warehousing and storage	12.57	1.55	**14.12**	12.57	1.45	**14.02**
Publishing industries (includes software)	3.30	4.37	**7.68**	3.30	4.22	**7.52**
Motion picture and sound recording industries	4.41	3.13	**7.54**	4.40	3.03	**7.44**
Broadcasting and telecommunications	2.31	3.55	**5.86**	2.29	3.37	**5.66**
Information and data processing services	2.57	5.34	**7.91**	2.57	5.37	**7.94**
Federal Reserve banks, credit intermediation, and related activities	4.09	2.05	**6.13**	4.09	2.04	**6.13**
Securities, commodity contracts, and investments	2.35	2.64	**4.99**	2.33	2.50	**4.83**
Insurance carriers and related activities	5.70	1.37	**7.07**	5.60	1.27	**6.88**
Funds, trusts, and other financial vehicles	0.90	4.43	**5.33**	0.90	4.43	**5.33**
Real estate	0.71	2.29	**3.00**	0.70	2.16	**2.86**
Rental and leasing services and lessors of intangible assets	2.33	4.13	**6.46**	2.33	4.00	**6.33**
Legal services	4.97	2.16	**7.13**	4.96	2.01	**6.96**
Miscellaneous professional, scientific and technical services	5.38	3.21	**8.60**	5.27	2.87	**8.14**
Computer systems design and related services	6.24	2.67	**8.91**	6.24	2.47	**8.70**
Management of companies and enterprises	4.40	2.82	**7.22**	4.40	2.58	**6.98**
Administrative and support services	13.80	2.48	**16.28**	13.75	2.31	**16.06**
Waste management and remediation services	5.24	4.21	**9.45**	5.14	3.78	**8.92**
Educational services	13.10	2.84	**15.94**	13.09	2.50	**15.59**
Ambulatory health care services	7.32	2.60	**9.91**	7.31	2.41	**9.72**
Hospitals and nursing and residential care facilities	10.44	3.65	**14.09**	10.44	3.45	**13.89**
Social assistance	18.00	3.09	**21.08**	18.00	2.90	**20.90**
(continued on next page)						

(continued from previous page)						
Performing arts, spectator sports, museums, and related activities	5.50	2.30	**7.80**	5.48	2.16	**7.63**
Amusements, gambling, and recreation industries	11.83	2.78	**14.60**	11.83	2.63	**14.45**
Accommodation	9.09	3.39	**12.48**	9.08	3.19	**12.27**
Food services and drinking places	15.53	3.78	**19.31**	15.52	3.56	**19.08**
Other services, except government	10.53	3.68	**14.21**	10.52	3.50	**14.03**
Federal government enterprises	7.54	2.27	**9.81**	7.52	3.07	**10.59**
Federal general government	4.09	3.64	**7.73**	4.10	2.55	**6.65**
State and local government enterprises	4.77	4.48	**9.25**	4.73	3.73	**8.46**
State and local general government	9.35	2.88	**12.23**	9.41	3.31	**12.71**
REEE	n/a	n/a	n/a	5.24	2.06	**7.29**
Average Employment Multiplier	5.78	3.50	**9.28**	5.76	3.37	**9.13**
Average Manufacturing Multiplier	4.43	4.40	**8.83**	4.43	4.36	**8.79**
Average Non-Manufacturing Multiplier	6.34	3.13	**9.47**	6.32	2.98	**9.30**

Table 12: Total Employment Multipliers for Original, 65x65, and 68x68 I-O Tables

	Total Employment Multipliers (FTE Employment per $1 million demand)		
	Original (65x65)	Single REEE Industry (66x66)	Three Distinct REEE Industries (68x68)
Farms	7.48	6.51	6.52
Forestry, fishing, and related activities	16.23	15.79	15.82
Oil and gas extraction	2.26	2.18	2.18
Mining, except oil and gas	5.59	5.50	5.51
Support activities for mining	5.73	5.49	5.50
Utilities	2.90	2.79	2.79
Construction	10.69	10.58	10.58
Food and beverage and tobacco products	8.60	8.16	8.16
Textile mills and textile product mills	10.48	10.62	10.62
Apparel and leather and allied products	13.88	13.93	13.92
Wood products	13.06	12.85	12.88
Paper products	8.04	8.43	8.43
Printing and related support activities	10.72	10.75	10.76
Petroleum and coal products	3.06	2.99	2.98
Chemical products	5.44	5.34	5.34
Plastics and rubber products	8.61	8.53	8.53
Nonmetallic mineral products	8.18	8.11	7.74
Primary metals	6.50	7.08	7.08
Fabricated metal products	9.25	9.14	9.14
Machinery	8.61	8.36	8.74
Computer and electronic products	8.27	8.35	8.35
Electrical equipment, appliances, and components	7.59	7.41	7.41
Motor vehicles, bodies and trailers, and parts	8.95	9.00	9.03
Other transportation equipment	7.99	7.77	7.77
Furniture and related products	11.83	11.83	11.83
Miscellaneous manufacturing	8.71	8.48	8.03
Wholesale trade	7.53	7.43	7.42
Retail trade	12.87	12.75	12.75
Air transportation	7.39	7.77	7.76
Rail transportation	6.10	5.98	5.99
Water transportation	7.10	7.57	7.57
Truck transportation	9.54	9.41	9.41
Transit and ground passenger transportation	16.46	16.32	16.32
			(continued on next page)

(continued from previous page)			
Pipeline transportation	4.87	4.70	4.70
Other transportation and support activities	10.70	10.62	10.62
Warehousing and storage	14.12	14.02	14.02
Publishing industries (includes software)	7.68	7.52	7.51
Motion picture and sound recording industries	7.54	7.44	7.43
Broadcasting and telecommunications	5.86	5.66	5.65
Information and data processing services	7.91	7.94	7.93
Federal Reserve banks, credit intermediation, and related activities	6.13	6.13	6.13
Securities, commodity contracts, and investments	4.99	4.83	4.82
Insurance carriers and related activities	7.07	6.88	6.87
Funds, trusts, and other financial vehicles	5.33	5.33	5.32
Real estate	3.00	2.86	2.86
Rental and leasing services and lessors of intangible assets	6.46	6.33	6.32
Legal services	7.13	6.96	6.96
Miscellaneous professional, scientific and technical services	8.60	8.14	8.00
Computer systems design and related services	8.91	8.70	8.70
Management of companies and enterprises	7.22	6.98	6.97
Administrative and support services	16.28	16.06	16.06
Waste management and remediation services	9.45	8.92	8.92
Educational services	15.94	15.59	15.58
Ambulatory health care services	9.91	9.72	9.71
Hospitals and nursing and residential care facilities	14.09	13.89	13.88
Social assistance	21.08	20.90	20.89
Performing arts, spectator sports, museums, and related activities	7.80	7.63	7.63
Amusements, gambling, and recreation industries	14.60	14.45	14.45
Accommodation	12.48	12.27	12.27
Food services and drinking places	19.31	19.08	19.07
Other services, except government	14.21	14.03	14.03
(continued on next page)			

(continued from previous page)			
Federal government enterprises	9.81	10.59	10.58
Federal general government	7.73	6.65	6.66
State and local government enterprises	9.25	8.46	8.46
State and local general government	12.23	12.71	12.71
REEE	n/a	7.29	n/a
RE Production & Sales	n/a	n/a	6.96
Energy Services	n/a	n/a	6.73
Green Building	n/a	n/a	10.17
Average Employment Multiplier	9.28	9.13	9.09

Table 13: Composition of Synthetic REEE Industries

	Synthetic Industry						
Existing I-O Industry (65-industry level)	Weatherization	Mass Transit & Freight Rail	Smart Grid	Wind	Solar	Biomass	Green Program
Farm products (unprocessed)	0.0%	0.0%	0.0%	0.0%	0.0%	25.0%	2.50%
Forestry, fishing and related	0.0%	0.0%	0.0%	0.0%	0.0%	25.0%	2.50%
Construction	100.0%	45.0%	25.0%	26.0%	30.0%	25.0%	59.60%
Chemical products	0.0%	0.0%	0.0%	0.0%	0.0%	12.5%	1.25%
Plastics and rubber products	0.0%	0.0%	0.0%	12.0%	0.0%	0.0%	1.20%
Fabricated metal products	0.0%	0.0%	0.0%	12.0%	17.5%	0.0%	2.95%
Machinery	0.0%	0.0%	25.0%	37.0%	0.0%	0.0%	6.20%
Computer and electronic products	0.0%	0.0%	25.0%	3.0%	17.5%	0.0%	4.55%
Electrical equipment, appliances, and components	0.0%	0.0%	25.0%	3.0%	17.5%	0.0%	4.55%
Rail transportation	0.0%	10.0%	0.0%	0.0%	0.0%	0.0%	2.00%
Transit and ground passenger transportation	0.0%	45.0%	0.0%	0.0%	0.0%	0.0%	9.00%
Miscellaneous professional, scientific and technical services	0.0%	0.0%	0.0%	7.0%	17.5%	12.5%	3.70%

Note: The industries with zero values in all categories have been suppressed in this table.

Table 14: Employment Multipliers of Various REEE Industries Using Synthetic Approach

	FTE Employment per $1 million demand Using original 65-industry I-O table		
	Direct	Indirect	Total
Weatherization	6.13	4.56	10.69
Mass Transit & Freight Rail	9.12	3.71	12.83
Smart Grid	4.54	4.25	8.79
Wind	4.85	4.33	9.19
Solar	5.15	3.96	9.11
Biomass	6.68	3.67	10.36
"Green Program"	6.40	4.19	10.59

Table 15: Composition of Industries Using Hybrid Approach

	Renewable Energy	**Energy Services**	**Green Building**	**REEE**
Forestry, fishing and related	0.05%	0.00%	1.12%	0.18%
Construction	16.00%	0.08%	28.53%	7.17%
Food and beverage and tobacco products	0.23%	0.00%	0.00%	0.04%
Textile mills and textile product mills	0.01%	0.00%	0.00%	0.00%
Wood products	0.03%	0.54%	0.74%	0.48%
Chemical products	1.44%	0.02%	0.19%	0.30%
Plastics and rubber products	0.08%	0.09%	0.20%	0.10%
Nonmetallic mineral products	5.75%	0.00%	43.93%	7.63%
Fabricated metal products	8.80%	0.00%	0.24%	1.59%
Machinery	3.12%	0.00%	0.00%	0.55%
Computer and electronic products	0.79%	0.00%	0.00%	0.14%
Electrical equipment, appliances, and components	9.57%	0.00%	0.00%	1.69%
Miscellaneous manufacturing	43.05%	1.85%	1.39%	9.05%
Air transportation	0.06%	0.00%	0.00%	0.01%
Truck transportation	0.01%	0.00%	0.52%	0.08%
Transit and ground passenger transportation	0.02%	0.00%	0.00%	0.00%
Other transportation and support activities	0.07%	0.00%	0.00%	0.01%
Publishing industries (includes software)	0.02%	0.14%	0.00%	0.10%
Information and data processing services	0.00%	0.01%	0.00%	0.00%
Funds, trusts, and other financial vehicles	0.04%	0.00%	0.00%	0.01%
Miscellaneous professional, scientific and technical services	1.19%	30.09%	22.91%	23.91%
Waste management and remediation services	0.00%	53.16%	0.00%	35.78%
Educational services	0.01%	13.77%	0.25%	9.31%

(continued on next page)

(continued from previous page)				
Amusements, gambling, and recreation industries	0.06%	0.00%	0.00%	0.01%
Accommodation	0.00%	0.02%	0.00%	0.01%
Federal general government	9.46%	0.11%	0.00%	1.74%
State and local general government	0.13%	0.14%	0.00%	0.11%

Table 16: Employment Multipliers Using Hybrid Approach –
Survey Responses as Demand Stimulus

	Direct	Indirect	Total
RE Production & Sales	4.74	4.06	**8.81**
Energy Services	6.36	3.73	**10.09**
Green Building	5.31	3.84	**9.15**
REEE	5.92	3.80	**9.72**

Table 17: Specification Tests for the Green Program

Green Program Specification	**Share of Manufacturing Industries**	**Share of non-Manufacturing Industries**	**Total Employment Multiplier**	**Percentage Point Change in Share of Manufacturing versus Non-Manufacturing**	**Percentage Change in Total Employment Multiplier**
Original	20.7%	79.3%	10.59	--	
Alt 1	30.7%	69.3%	10.29	10 (more mfg)	-2.83%
Alt 2	10.7%	89.3%	10.89	10 (less mfg)	2.83%
Alt 3	40.7%	59.3%	9.99	20 (more mfg)	-5.66%
Alt 4	0.7%	99.3%	11.19	20 (less mfg)	5.66%
Alt 5	50.7%	49.3%	9.69	30 (more mfg)	-8.49%

Table 18: Specification Tests for the REEE Industry

REEE Industry Specification	**Share of Manufacturing Industries**	**Share of non-Manufacturing Industries**	**Total Employment Multiplier**	**Percentage Point Change in Share of Manufacturing versus Non-Manufacturing**	**Percentage Change in Total Employment Multiplier**
Original	21.6%	78.4%	9.72	--	
Alt 1	31.6%	68.4%	9.57	10 (more mfg)	-1.57%
Alt 2	11.6%	88.4%	9.88	10 (less mfg)	1.57%
Alt 3	41.6%	58.4%	9.42	20 (more mfg)	-3.15%
Alt 4	1.6%	98.4%	10.03	20 (less mfg)	3.15%
Alt 5	51.6%	48.4%	9.26	30 (more mfg)	-4.72%

Table 19: Employment Multipliers from Integrated, Synthetic, and Hybrid Approaches

	Direct FTE employment per $1 million demand	Indirect FTE employment per $1 million demand	**Total FTE employment per $1 million demand**
Renewable Energy and Energy Efficiency			
REEE (66x66)	5.24	2.06	**7.29**
REEE (Hybrid)	5.92	3.80	**9.72**
Green Program (Synthetic)	6.40	4.19	**10.59**
Renewable Energy Production and Sales			
RE Production & Sales (68x68)	3.19	3.77	**6.96**
RE Production & Sales (Hybrid)	4.74	4.06	**8.81**
Energy Services			
Energy Services (68x68)	5.56	1.17	**6.73**
Energy Services (Hybrid)	6.36	3.73	**10.09**
Green Building/Weatherization			
Green Building (68x68)	5.97	4.21	**10.17**
Building Weatherization (Synthetic)	6.13	4.56	**10.69**
Green Building (Hybrid)	5.31	3.84	**9.15**

Table 20: Comparison with REEE multipliers from previous studies

Study	Industry or Industry Group	Employment Multiplier	
Direct Employment Only			
Singh and Fehrs (2001)	Wind, solar pv, coal	5.70 jobs/$1M (wind); 5.65 jobs/$1M (solar); 3.96 jobs/$1M (coal)	Direct only
Sterzinger (2006)	Wind, solar, geothermal, biomass	5.30 jobs/$1 million	Direct only
Direct plus Indirect Employment			
EWEA (2004)	Wind (Europe)	11.21 jobs/€1 million[44]	Direct + indirect
Pollin, Heintz, Garrett-Peltier (2009)	Green Program (various efficiency and renewables)	11.93 jobs/$1 million	Direct+ indirect
Bezdek (2009)	Various REEE	8.61 jobs/$1 million	Direct + indirect
Laitner et al (2007)	Efficiency only	13.50 jobs/$1 million	Direct + indirect
"Green Program" (synthetic)	Efficiency, wind, solar, biomass	10.59 jobs/$1 million	Direct + indirect
REEE (hybrid)	Various renewables and efficiency	9.72 jobs/$1 million	Direct + indirect
REEE (integrated)	Various renewables and efficiency	7.29 jobs/$1 million	Direct + indirect
Direct, Indirect, and Induced Employment			
Pollin, Heintz, Garrett-Peltier (2009)	Green Program (various efficiency and renewables)	16.70 jobs/$1 million (as reported)	Direct, indirect, induced
Roland-Holst (2008)	Efficiency only	26.81 jobs/$1 million	Direct, indirect, induced

[44] Over the course of 2002, which the EWEA used as a base year for this multiplier, the Euro and the U.S. dollar exchanged for nearly 1 to 1, therefore we can compare this estimate to a jobs-per-dollar estimate.

Table 21: Output Multipliers from Leontief Inverse Matrices

	Original BEA 65-Industry Matrix				Expanded 66x66 Matrix				Expanded 68x68 Matrix		
	Direct	Indirect	Total		Direct	Indirect	Total		Direct	Indirect	Total
	Dollars of output resulting from a $1 increase in demand										
Farms	1.20	1.17	2.36		1.16	0.94	2.10		1.16	0.94	2.10
Forestry, fishing, and related activities	1.46	0.61	2.07		1.42	0.58	2.00		1.42	0.59	2.01
Oil and gas extraction	1.20	0.45	1.65		1.20	0.43	1.63		1.20	0.43	1.63
Mining, except oil and gas	1.11	0.71	1.82		1.11	0.68	1.79		1.11	0.69	1.80
Support activities for mining	1.01	0.97	1.97		1.00	0.90	1.90		1.00	0.90	1.91
Utilities	1.01	0.73	1.74		1.01	0.69	1.69		1.01	0.69	1.69
Construction	1.00	1.01	2.01		1.00	0.98	1.98		1.00	0.98	1.98
Food and beverage and tobacco products	1.19	1.44	2.62		1.18	1.33	2.50		1.18	1.33	2.50
Textile mills and textile product mills	1.23	1.27	2.50		1.23	1.29	2.53		1.23	1.30	2.53
Apparel and leather and allied products	1.09	0.93	2.01		1.09	0.93	2.02		1.09	0.93	2.02
Wood products	1.28	1.20	2.48		1.27	1.18	2.45		1.27	1.18	2.45
Paper products	1.25	1.08	2.32		1.27	1.15	2.42		1.27	1.15	2.42
Printing and related support activities	1.04	1.04	2.07		1.04	1.04	2.08		1.04	1.05	2.08
Petroleum and coal products	1.12	1.41	2.53		1.12	1.39	2.51		1.12	1.39	2.51
Chemical products	1.35	0.95	2.30		1.34	0.93	2.27		1.34	0.93	2.27
Plastics and rubber products	1.08	1.39	2.47		1.08	1.37	2.44		1.08	1.37	2.45
Nonmetallic mineral products	1.12	0.93	2.05		1.11	0.91	2.02		1.09	0.84	1.93
Primary metals	1.41	0.89	2.30		1.47	0.99	2.46		1.47	1.00	2.46
Fabricated metal products	1.13	1.06	2.18		1.12	1.04	2.15		1.12	1.04	2.16
Machinery	1.09	1.18	2.27		1.08	1.13	2.21		1.09	1.22	2.31
Computer and electronic products	1.23	0.95	2.17		1.23	0.96	2.19		1.23	0.96	2.20
Electrical equipment, appliances, and components	1.06	1.00	2.06		1.05	0.96	2.01		1.05	0.96	2.01
Motor vehicles, bodies and trailers, and parts	1.42	1.43	2.85		1.42	1.44	2.87		1.42	1.46	2.88
Other transportation equipment	1.12	1.02	2.15		1.12	0.97	2.09		1.12	0.98	2.10
Furniture and related products	1.02	1.18	2.20		1.02	1.18	2.20		1.02	1.18	2.20
Miscellaneous manufacturing	1.06	1.05	2.11		1.05	1.00	2.05		1.04	0.90	1.94
Wholesale trade	1.04	0.46	1.50		1.04	0.44	1.48		1.04	0.44	1.48
Retail trade	1.01	0.58	1.58		1.01	0.55	1.56		1.01	0.55	1.55
Air transportation	1.00	1.06	2.07		1.00	1.15	2.16		1.00	1.15	2.16
Rail transportation	1.00	0.79	1.79		1.00	0.76	1.76		1.00	0.76	1.76
Water transportation	1.00	1.10	2.10		1.00	1.18	2.18		1.00	1.18	2.18

(continued on next page)

(continued from previous page)

Truck transportation	1.15	0.93	2.08		1.15	0.90	2.05		1.15	0.90	2.05
Transit and ground passenger transportation	1.03	0.80	1.82		1.03	0.76	1.78		1.03	0.76	1.78
Pipeline transportation	1.02	1.17	2.19		1.02	1.14	2.16		1.02	1.14	2.16
Other transportation and support activities	1.04	0.43	1.47		1.04	0.41	1.45		1.04	0.41	1.45
Warehousing and storage	1.00	0.41	1.41		1.00	0.38	1.38		1.00	0.38	1.38
Publishing industries (includes software)	1.07	0.91	1.98		1.07	0.88	1.95		1.07	0.88	1.95
Motion picture and sound recording industries	1.32	0.71	2.03		1.31	0.69	2.01		1.31	0.69	2.01
Broadcasting and telecommunications	1.34	0.77	2.11		1.33	0.73	2.06		1.33	0.73	2.06
Information and data processing services	1.04	1.07	2.11		1.04	1.08	2.12		1.04	1.08	2.12
Federal Reserve banks, credit intermediation, and related activities	1.08	0.45	1.53		1.08	0.46	1.53		1.08	0.45	1.53
Securities, commodity contracts, and investments	1.24	0.59	1.84		1.23	0.56	1.80		1.23	0.56	1.80
Insurance carriers and related activities	1.58	0.38	1.97		1.56	0.36	1.92		1.56	0.36	1.92
Funds, trusts, and other financial vehicles	1.01	1.44	2.44		1.01	1.45	2.46		1.01	1.45	2.46
Real estate	1.06	0.44	1.49		1.05	0.41	1.46		1.05	0.41	1.46
Rental and leasing services and lessors of intangible assets	1.03	0.81	1.84		1.03	0.78	1.81		1.03	0.78	1.81
Legal services	1.04	0.46	1.50		1.04	0.43	1.47		1.04	0.43	1.46
Miscellaneous professional, scientific and technical services	1.13	0.64	1.77		1.10	0.57	1.68		1.10	0.55	1.65
Computer systems design and related services	1.01	0.48	1.48		1.01	0.44	1.45		1.01	0.44	1.45
Management of companies and enterprises	1.01	0.70	1.70		1.01	0.64	1.64		1.01	0.64	1.64
Administrative and support services	1.07	0.62	1.69		1.07	0.58	1.65		1.07	0.58	1.65
Waste management and remediation services	1.13	1.04	2.17		1.11	0.95	2.06		1.11	0.95	2.06
Educational services	1.01	0.68	1.68		1.01	0.60	1.61		1.01	0.60	1.61
Ambulatory health care services	1.02	0.57	1.58		1.01	0.53	1.54		1.01	0.53	1.54
Hospitals and nursing and residential care facilities	1.00	0.84	1.84		1.00	0.80	1.80		1.00	0.79	1.79
Social assistance	1.00	0.73	1.73		1.00	0.69	1.69		1.00	0.69	1.69

(continued on next page)

(continued from previous page)

Performing arts, spectator sports, museums, and related activities	1.17	0.48	1.65		1.16	0.45	1.61		1.16	0.45	1.61
Amusements, gambling, and recreation industries	1.00	0.64	1.64		1.00	0.60	1.60		1.00	0.60	1.60
Accommodation	1.00	0.72	1.72		1.00	0.67	1.67		1.00	0.67	1.67
Food services and drinking places	1.01	1.03	2.04		1.01	0.97	1.98		1.01	0.97	1.98
Other services, except government	1.02	0.91	1.93		1.02	0.86	1.89		1.02	0.87	1.89
Federal government enterprises	1.00	0.56	1.57		1.00	0.67	1.68		1.00	0.67	1.67
Federal general government	1.00	0.79	1.79		1.00	0.63	1.63		1.00	0.63	1.64
State and local government enterprises	1.02	1.18	2.19		1.01	0.88	1.89		1.01	0.88	1.89
State and local general government	1.01	0.69	1.70		1.01	0.88	1.89		1.01	0.88	1.89
REEE	n/a	n/a	n/a		1.01	0.46	1.47		n/a	n/a	n/a
RE Production & Sales	n/a	n/a	n/a		n/a	n/a	n/a		1.01	0.93	1.94
Energy Services	n/a	n/a	n/a		n/a	n/a	n/a		1.00	0.25	1.25
Green Building	n/a	n/a	n/a		n/a	n/a	n/a		1.01	0.91	1.92
Average for all Industries	1.11	0.86	1.97		1.10	0.83	1.93		1.10	0.83	1.93

Table 22: Source of Variation in REEE Employment Multipliers

Industry	**Total Employment Multiplier** (FTE Employment per $1 million demand, from Employment Requirements Table)	**Total Output Multiplier** (dollars total output economy-wide/dollar of demand for industry)	**Employment /Output Ratio** (FTE Employment per $1 million sales)	**Source of Deviation from Industry Average**	
				Output Multiplier	E/O ratio
REEE	7.29	1.47	5.18	Lower	Lower
RE Production & Sales	6.96	1.94	3.16	--	Lower
Energy Services	6.73	1.25	5.54	Lower	--
Green Building	10.17	1.92	5.92	--	Higher
Industry Average	(66x66) 9.13 (68x68) 9.09	1.93	5.35	--	

Table 23: REEE Employment Multipliers Using Industry Average E/O Ratio

Industry	**Total Employment Multiplier (original)**	**Employment/Output Ratio (original)**	**Total Employment Multiplier (using average E/O)**
REEE	7.29	5.18	7.49
RE Production & Sales	6.96	3.16	9.16
Energy Services	6.73	5.54	6.54
Green Building	10.17	5.92	9.61
Industry Average	(66x66) 9.13 (68x68) 9.09	5.37	(66x66) 9.13 (68x68) 9.12

Table 24: Comparison of Sources of Variation in Employment Multipliers Between Integrated and Synthetic Approaches

Industry	**Total Employment Multiplier**	**Total Output Multiplier**	**Employment/Output Ratio**	**Source of Deviation from Industry Average**
Synthetic Industry				
Green Program	10.59	2.03	6.11	Higher output multiplier, Higher E/O ratio
Building Weatherization	10.69	2.01	6.10	Higher output multiplier, Higher E/O ratio
Industry Average	9.28	1.97	5.37	--
Integrated Industry				
REEE	7.29	1.47	5.18	Lower output multiplier, Lower E/O ratio
Green Building	10.17	1.92	5.92	Higher E/O ratio
Industry Average	9.13 (66x66) 9.09 (68x68)	1.93	5.37	--

Table 25: Differences in Composition of Final Demand for REEE and Green Program

	Composition of Survey Sales	Composition of Green Program	Difference	Difference more than 5 percentage points?
Farm products (unprocessed)	0.000%	2.500%	-2.500%	No
Forestry, fishing and related	0.177%	2.500%	-2.323%	No
Construction	**7.166%**	**59.600%**	**-52.434%**	**Yes**
Food and beverage and tobacco products	0.040%	0.000%	0.040%	No
Textile mills and textile product mills	0.003%	0.000%	0.003%	No
Wood products	0.479%	0.000%	0.479%	No
Paper products	0.001%	0.000%	0.001%	No
Chemical products	0.297%	1.250%	-0.953%	No
Plastics and rubber products	0.105%	1.200%	-1.095%	No
Nonmetallic mineral products	**7.627%**	**0.000%**	**7.627%**	**Yes**
Fabricated metal products	1.589%	2.950%	-1.361%	No
Machinery	**0.550%**	**6.200%**	**-5.650%**	**Yes**
Computer and electronic products	0.140%	4.550%	-4.410%	No
Electrical equipment, appliances, and components	1.688%	4.550%	-2.862%	No
Miscellaneous manufacturing	**9.045%**	**0.000%**	**9.045%**	**Yes**
Air transportation	0.010%	0.000%	0.010%	No
Rail transportation	0.000%	2.000%	-2.000%	No
Truck transportation	0.080%	0.000%	0.080%	No
Transit and ground passenger transportation	**0.003%**	**9.000%**	**-8.997%**	**Yes**
Other transportation and support activities	0.012%	0.000%	0.012%	No
Publishing industries (includes software)	0.096%	0.000%	0.096%	No
Information and data processing services	0.005%	0.000%	0.005%	No
Funds, trusts, and other financial vehicles	0.008%	0.000%	0.008%	No
Miscellaneous professional, scientific and technical services	**23.909%**	**3.700%**	**20.209%**	**Yes**
Waste management and remediation services	**35.783%**	**0.000%**	**35.783%**	**Yes**
Educational services	**9.306%**	**0.000%**	**9.306%**	**Yes**
Amusements, gambling, and recreation industries	0.011%	0.000%	0.011%	No
Accommodation	0.012%	0.000%	0.012%	No
Federal general government	1.743%	0.000%	1.743%	No
State and local general government	0.115%	0.000%	0.115%	No

Table 26: Comparison of Fossil Fuel and REEE Employment Multipliers

Industry (65x65)	***Direct FTE employment per $1 million demand***	***Indirect FTE employment per $1 million demand***	***Total FTE employment per $1 million demand***
Oil and gas extraction	0.64	1.62	**2.26**
Mining, except oil and gas	3.24	2.35	**5.59**
Support activities for mining	2.20	3.53	**5.74**
Utilities	1.22	1.68	**2.90**
Petroleum and Coal Products	0.23	2.82	**3.06**
"Green Program" (synthetic)	6.40	4.19	**10.59**
REEE (hybrid)	5.92	3.80	**9.72**
REEE (integrated)	5.24	2.06	**7.29**

TABLE 4

Employment impacts of alternative energy sources

Job creation per $1 million in output

Energy source	Direct job creation per $1 million in output (# of jobs)	Indirect job creation per $1 million in output (# of jobs)	Direct and indirect job creation per $1 million in output (# of jobs)	Direct and indirect job creation relative to oil (% difference)
Fossil fuels				
Oil and natural gas	0.8	2.9	3.7	–
Coal	1.9	3.0	4.9	+32.4%
Energy efficiency				
Building retrofits	7.0	4.9	11.9	+221.6%
Mass transit/freight rail (90% MT, 10% FR)	11.0	4.9	15.9	+329.7%
Smart grid	4.3	4.6	8.9	+140.5%
Renewables				
Wind	4.6	4.9	9.5	+156.8%
Solar	5.4	4.4	9.8	+164.9%
Biomass	7.4	5.0	12.4	+235.1%

Figure 1: Employment impacts of alternative energy sources, Table 4 from (Pollin, Heintz, & Garrett-Peltier, 2009)

Biomass

25 percent	grain farming
25 percent	logging
25 percent	other new construction
12.5 percent	refining
12.5 percent	scientific R&D

Building weatherization

50 percent	nonresidential repair construction
50 percent	residential repair construction

Coal

44 percent	coal mining
08 percent	support activities for coal mining
48 percent	coal product manufacturing

Oil and gas

23 percent	oil and gas extraction
07 percent	drilling oil and gas wells
04 percent	support activities for oil and gas extraction
10 percent	natural gas distribution
45 percent	petroleum refineries
08 percent	petroleum product manufacturing
03 percent	pipeline transport

Smart grid

25 percent	construction
25 percent	machinery
25 percent	electronic equipment
12.5 percent	electrical power goods
12.5 percent	storage batteries

Solar

30 percent	construction
17.5 percent	hardware manufacturing
17.5 percent	electrical equipment
17.5 percent	electronic components
17.5 percent	scientific and technical services

Transit and rail

45 percent	other construction
10 percent	rail transportation
45 percent	ground passenger transportation

Wind

26 percent	construction
12 percent	plastic products
12 percent	fabricated metal
37 percent	machinery
03 percent	mechanical power transmission equipment
03 percent	electronic components
07 percent	scientific and technical services

"Green program"

40 percent	building weatherization
20 percent	transit and rail
10 percent	smart grid
10 percent	wind
10 percent	solar
10 percent	biomass

Figure 2: Energy Industries and Weights, from (Pollin, Heintz, & Garrett-Peltier, 2009)

APPENDIX

SURVEY QUESTIONNAIRE

ID

Renewable Energy and Energy Efficiency Survey of Employment, Sales and Costs

*The information provided in this questionnaire is **completely confidential**. The data wil be aggregated with data of other similar businesses, so that any publicly released data will not be traceable to the individual businesses who respond to this survey.*

PLEASE RETURN BY **May 16, 2008**

Any questions, please call (413) 577-0818 or email green_survey@peri.umass.edu

Reporting Instructions:

This questionnaire is designed to assess the purchases and sales made by businesses in the renewable energy and energy efficiency sector. Please read the instructions in each section carefully. Provide exact figures when possible and reasonable estimates in other cases. PLEASE RESPOND TO ALL QUESTIONS.

Please provide information for the year **2005** if possible. If not possible, please provide information for 2006 or 2007 (or a recent fiscal year which does not correspond to a calendar year), and please note the year for which the information is provided.

Year of Reporting

Information from calendar year ending…		Or, information from fiscal year ending…	

Item 1: Business Type

1a. What is the primary purpose of your business? What do you produce or what type of service do you offer?

1b. Please mark an "X" next to the ownership structure that best corresponds to your business:

	Private – Corporate
	Private – Partnership/Proprietorship
	Private - Cooperative
	Publicly traded
	Non-Profit - Cooperative
	Non-profit

	Government
	Other (please describe)

Item 2: Employment

	Enter amount here
2a. Number of Employees at the end of 2005 (or end of fiscal year for which you are reporting)	
2b. Total compensation for employees in 2005	
Total Wages	$
Total Benefits	$

2c. Employment by occupation. Next to each occupational category below, please list the number of persons employed in each occupation. Please separate full-time and part-time, and list how many hours (on average) a part-time employee works.

Occupational Category	# of Full-time employees in this position	# of Part-time employees in this position	Average # of weekly hours worked by a P/T employee (per occupation)
Management			
Business and Financial Operations			
Computer and Math Occupations			
Architecture & Engineering			
Life, Physical and Social Science			
Community and Social Service			
Legal			
Education and Training			
Arts, Design, Entertainment, Sports			
Healthcare			
Healthcare Support			
Protective Service			
Food Prep and Related			
Cleaning and Maintenance			
Personal Care			
Sales and Related			
Office and Administrative Support			
Farming, Fishing, Forestry			
Construction/Extraction			
Installation, Maintenance, Repair			
Production			
Transportation and Moving			
Military-specific occupations			
Other (please list occupational titles)			

Item 3: Expenditures and Sales

3a. Goods: Purchases and Sales of Supplies, Materials and Investment Goods

Please enter the total dollar value of goods purchased and sold in 2005 (or year for which you are reporting). You may round to nearest $1,000.

Please specify whether the goods were purchased from or sold to domestic or international sources.

If no purchases/sales were made in a category, leave the cell blank.

	Purchases		**Sales**	
	U.S.	**Imports**	**U.S.**	**Exports**
Raw Materials				
Farm products (unprocessed)				
Forestry, fishing and related				
Manufactured goods				
Wood products				
Nonmetallic mineral products (for example:brick, ceramic tile, glass products, etc.)				
Primary metals				
Fabricated metal products				
Miscellaneous manufacturing				
Food and beverage and tobacco products				
Textile products				
Apparel and leather and allied products				
Paper products				
Petroleum and coal products, not for energy generation (for example: asphalt, waxes, lubricants)				
Chemical products				
Plastics and Rubber products				
Investment Goods				
Machinery				
Computer and electronic products				
Electrical equipment, appliances and components				
Motor vehicles, bodies and trailers				
Other transportation equipment				
Furniture and related products				

3b. Services: Purchases and Sales

Please enter the total dollar value of services purchased and sold in year for which you are reporting. You may round to nearest $1,000.

Please specify if services were purchased from or sold to domestic or international sources.

If no purchases/sales were made in a category, leave the cell blank.

	Purchases		**Sales**	
	U.S.	**Imports**	**U.S.**	**Exports**
Construction				
Transportation				

Air Transportation				
Rail Transportation				
Water Transportation				
Truck Transportation				
Transit and Ground Passenger Transportation				
Pipeline Transportation				
Other transportation				
Warehousing and Storage				
Information	U.S. (P)	Imports	U.S. (S)	Exports
Publishing Industries (incl. software)				
Motion picture and sound recording				
Broadcasting and telecommunications				
Information and data processing services				
Finance and Insurance				
Insurance (DO NOT include here health insurance costs already listed above)				
Financing and banking				
Real Estate				
Professional and Business Services				
Legal Services				
Accounting and Bookkeeping				
Advertising/Marketing and related				
Computer Systems design and related				
Architecture/Engineering				
Scientific R & D				
Misc. Scientific, Professional and Technical Services				
Management of companies				
Administrative and Support Services				
Waste Management				
Educational Services				
Health Care Services				
Arts, Entertainment and Recreation				
Accommodation				
Food Services				
Federal Government services				
State/local government services				

3c. Annual Revenues and Expenses

Please enter the total amount of revenues and expenses in year for which you are reporting. You may round to nearest $1,000. ***Please include totals from ALL PARTS of this questionnaire (including 4 and 5).***

Total Gross Revenue from all sources	$
Total Expenses	$

Item 4: Energy purchases and production

4a. Purchased Energy

Please enter the total dollar value of energy purchased in year for which you are reporting. You may round to nearest $1,000.

If no purchases were made in a category, leave the category blank.

If you did not purchase energy goods directly, but purchased electricity and heat, please list these purchases and identify the main source of energy if you know it.			
Oil			$
Natural Gas			$
Coal			$
Hydroelectric			$
Nuclear			$
Solar PV			$
Solar thermal			$
Wind			$
Geothermal			$
Biomass			
Solid Biomass fuels (e.g. sawdust, crop wastes)			$
Liquid Biomass fuels (e.g. biodiesel, ethanol)			$
Gaseous biomass fuels (e.g. biogas, methane)			$
Electricity (please identify major source if known)	Source:		$
Heat (please identify major source if known)	Source:		$
Renewable Energy Certificates/offsets (please identify type of energy source if known)			$
Other (please describe)			

4b. Produced Energy

Please enter below the total amount of energy your business produced both for its own use and for sale in year for which you are reporting. When possible, please list both the quantity of energy produced and the dollar value of energy produced.

	Production for sale (in $)	Production for sale (BTU or other physical units)	Production for own use (equivalent $ value)	Production for own use (BTU or other physical units)
Oil				
Natural Gas				
Coal				
Hydroelectric				
Nuclear				
Solar PV				
Solar thermal				
Wind				
Geothermal				
Biomass				
Solid biomass fuels				

Liquid biomass fuels				
Gaseous biomass fuels				

Item 5: Other Income and Expenses

5a. Other income and public support. *Please describe and list amounts and sources of any subsidies, tax credits, or other public support you received in year for which you are reporting.*

Description of Subsidy/Tax Incentive	U.S. State/Local	U.S. Federal	Foreign
(1)	$	$	$
(2)	$	$	$
(3)	$	$	$
(4)	$	$	$
(5)	$	$	$

5b. Other expenses. *Please enter the dollar value of other expenses incurred in year for which you are reporting.*

Lease and Rental Payments	$
Taxes and License Fees (except payroll taxes)	$
Payroll Taxes	$
Depreciation and Amortization Expenses	$
Interest Expense	$
Other (please describe)	

Item 6: Other relevant information. Please use this space or attach a separate sheet for explanations of items on the questionnaire or to add any additional information that you think might be relevant.

Item 7: Contact Information. Please list the name and contact information for the person or persons who filled out this survey, along with contact information for other persons in the business who could answer questions regarding its content. (Note: this section is optional, but may be useful in clarifying answers to survey questions and for contacting the relevant persons once results are tallied.)

Name	Phone	Email

Thank you very much for your cooperation! Please return this form by email to:
green_survey@peri.umass.edu
or by fax to: (413) 577-0261 or by mail to:
Political Economy Research Institute
Green Jobs Survey Project
418 N. Pleasant Street
Amherst, MA 01002

BIBLIOGRAPHY

Ackerman, F., Stanton, E., DeCanio, S., Goodstein, E., Howarth, R., Norgaard, R., et al. (2008). *The Economics of 350: The Benefits and Costs of Climate Stabilization.* Portland, OR: Economics for Equity and Environment.

American Solar Energy Society and Management Information Services, Inc. . (2008). *Defining, Estimating, and Forecasting the Renewable Energy Industries in the U.S. and Colorado.* Boulder, CO: American Solar Energy Society.

Berck, P., & Hoffman, S. (2002). Assessing the Employment Impacts of Environmental and Natural Resource Policy. *Environmental and Resource Economics , 22*, 133-156.

Bezdek, R. H. (2009). *Estimating the Jobs Impacts of Tackling Climate Change.* Boulder, CO: Management Information Systems Inc., for the American Solar Energy Society.

Clarke, L., Edmonds, J., Jacoby, H., Pitcher, H., Reilly, J., & Richels, R. (2007). *"Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations," Sub-Report 2.1A of Synthesis and Assessment Product 2.1 by the.* Washington, D.C.: Dept of Energy, Office of Biological & Environmental Research.

Ehrhardt-Martinez, K., & Laitner, J. A. (2008). *The Size of the U.S. Energy Efficiency Market: Generating a More Complete Picture.* Washington, D.C.: American Council for an Energy-Efficient Economy.

European Wind Energy Association. (2004). *Wind Energy - The Facts.* Retrieved 2006, from www.ewea.org/fileadmin/ewea_documents/documents/publications/WETF/WETF.pdf

Fawcett, A. A., Calvin, K. V., de la Chesnaye, F., Reilly, J. M., & Weyant, J. P. (2009). Overview of EMF 22 U.S. transition scenarios. *Energy Policy , 31*, S198-S211.

Groves, R. (2006). Experiments in Producing Non-Response Bias. *Public Opinion Quarterly , 70* (5), 720-735.

Hillebrand, B., Buttermann, H. G., Behringer, J. M., & Bleuel, M. (2006). The expansion of renewable energies and employment effects in Germany. *Energy Policy , 34*, 3484-3494.

Horowitz, K. J., & Planting, M. A. (2006). *Concepts and Methods of the Input-Output Accounts.* Washington, D.C.: Bureau of Economic Analysis, U.S. Dept. of Commerce.

Keeter, S., Kennedy, C., Dimock, M., Best, J., & Craighill, P. (2006). Gauging the Impact of Growing Non-Response on Estimates from a National RDD Telephone Survey. *Public Opinion Quarterly , 70* (5), 739-779.

Kim, S. j., Davis, V. A., Jacobson, A. M., & Lyndaker, A. S. (2008). *Annual Industry Accounts: Revised Statistics for 2005-2007.* Washington, D.C.: Bureau of Economic Analysis.

Laitner, J. A. (2009). *The Positive Economics of Climate Change Policies: What the Historical Evidence Can Tell Us.* Washington, D.C.: American Council for an Energy-Efficient Economy, ACEEE Report No. E095.

Laitner, J. A., Eldridge, M., & Elliot, R. N. (2007). *The Economic Benefits of an Energy Efficiency and Onsite Renewable Energy Strategy to Meet Growing Electricity Needs in Texas.* Washington, D.C.: American Council for an Energy-Efficient Economy, ACEEE Report #E076.

Leontief, W. (1986). *Input Output Economics, 2nd ed.* New York: Oxford University Press.

McKinsey & Company and The Conference Board. (2007). *Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost?* Syndney, Australia: McKinsey & Company.

McKinsey Global Institute. (2007). *Curbing Global Energy Demand Growth: The Energy Productivity Opportunity.* Syndney, Australia: McKinsey & Company.

McKinsey Global Institute. (2008). *The carbon productivity challenge: Curbing climate change and sustaining economic growth.* Sydney, Australia: McKinsey & Company.

Miller, R. E., & Blair, P. D. (1985). *Input-Output Analysis: Foundations and Extensions.* New Jersey: Prentice-Hall, Inc.

National Academy of Sciences. (2010 (pre-publication copy)). *Real Prospects for Energy Efficiency in the United States.* Washington, D.C.

Nordhaus, W. (2008). *A Question of Balance.* New Haven, CT: Yale University Press.

Paltsev, S., Reilly, J. M., Jacoby, H. D., & Morris, J. F. (2009). The cost of climate policy in the United States. *Energy Policy , 31,* S235-S243.

Parry, M., Canziani, O., Palutikof, J., van der Linden, P., Hanson, C., & Eds. (2007). *IPCC, 2007: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment.* Cambridge, UK: Cambridge University Press.

Pollin, R., & Garrett-Peltier, H. (2009). *The U.S. Employment Effects of Military and Domestic Spending Priorities: An Updated Analysis.* Amherst, MA and Washington D.C.: Political Economy Research Institute and the Institute for Policy Studies.

Pollin, R., Heintz, J., & Garrett-Peltier, H. (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.* Amherst, MA and Washington D.C.: Political Economy Research Institute and Center for American Progress.

Richardson, H. W. (1972). *Input-Output and Regional Economics.* New York: John Wiley and Sons.

Ross, M. T., Fawcett, A. A., & Clapp, C. S. (2009). U.S. climate mitigation pathways post-2012: Transition scenarios in ADAGE. *Energy Policy , 31*, S212-S222.

Salant, P., & Dillman, D. A. (1994). *How to Conduct Your Own Survey.* New York: John Wiley & Sons.

Schneider, S., Semenov, S., Patwardhan, A., Burton, I., Magadza, C., Oppenheimer, M., et al. (2007). Assessing Key Vulnerabilities and the Risk From Climate Change. In M. Parry, O. Canziani, J. Palutikof, P. van der Linden, & C. Hanson (Eds.), *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmnetal Panel on Climate Change* (pp. 779-810). Cambridge, UK: Cambridge University Press.

Scott, M. J., Roop, J. M., Schultz, R. W., Anderson, D. M., & Cort, K. A. (2008). The impact of DOE building technology energy efficiency programs on U.S. employment, income, and investment. *Energy Economics , 30*, 2283-2301.

Singh, V., & Fehrs, J. (2001). *The Work That Goes Into Renewable Energy.* Washington, D.C.: Renewable Energy Policy Project, REPP Report #13.

Stern, S. N. (2007). *The Economics of Climate Change: The Stern Review*. Cambridge, U.K.: Cambridge University Press.

Sterzinger, G. (2006). *Jobs and Renewable Energy Project: Final Technical Report* . Washington D.C.: Submitted to the U.S. Dept. of Energy by the Renewable Energy Policy Project.

Sterzinger, G., & Svrcek, M. (2005). *Component Manufacturing: Ohio's Future in the Renewable Energy Industry.* Washington, D.C.: Renewable Energy Policy Project.

Stone, R. (1961). *Input-Output and National Accounts.* Paris: Organisation for Economic Co-operation and Development.

Taylor, L. (. (1990). *Socially Relevant Policy Analysis: Structuralist Computable General Equilibrium Models for the Developing World.* Cambridge, MA: Massachusetts Institute of Technology.

The Perryman Group. (2003). *Redefining the Prospects for Sustainable Prosperity, Employment Expansion, and Environmental Quality in the US: An Assessment of the Economic Impact of the Initiatives Comprising the Apollo Project.* Waco, TX: Apollo Alliance.

U.S. Energy Information Administration. (2010). *Annual Energy Outlook 2010 Early Release.* Washington, D.C.

Wei, M., Patadia, S., & Kammen, D. (2010). Putting renewables and energy efficiency to work: How many jobs can the clean energy industry generate in the US? *Energy Policy , 38,* 919-931.