Renewable Energy in North Carolina

The Potential Supply Chain and Connections to Existing Renewable and Energy Efficiency Firms

KEITH G. DEBBAGE
University of North Carolina at Greensboro

JACOB F. KIDD
University of North Carolina at Greensboro

Although our understanding of industry cluster dynamics is fairly well developed, it is less clear whether renewable energy firms and related potential *suppliers co-locate in similar ways to other more established industries. Consequently, this paper should be primarily viewed as a first step in disentangling the co-locational tendencies of the renewable industry and related* potential *suppliers. Based on methodology and data developed by the Renewable Energy Policy Project and the North Carolina Sustainable Energy Association, we find that the geography of the* potential *renewable suppliers is tightly concentrated along the I-85 corridor between Charlotte, the Triad and the Research Triangle region with significant outposts in Hickory, Wilmington and especially Asheville. It also appears that the* potential *suppliers have co-locational preferences that overlap significantly with* actual *renewable energy and energy-efficiency firms already located in North Carolina. Less well understood is how these* potential *suppliers and renewable/energy-efficiency firms inter-relate regarding both potential knowledge spillover effects and the formation of formal and informal networks of production—a key area for future research.*

Aunque nuestro entendimiento de la dinámica de aglomeración de la industria está bastante desarrollado, no está tan claro si las empresas de energía renovables y sus potenciales suplidores se ubicarán de manera similar a otras industrias mejores establecidas. En consecuencia, este ensayo debe ser visto principalmente como un primer paso para descifrar las tendencias de co-localización de la industria de renovables y sus potenciales suplidores. Basado en la metodología y datos elaborado por el Proyecto de Política de Energía Renovable y la Asociación de Energía Sustentable de Carolina del Norte, encontramos que la geografía de los potenciales suplidores está fuertemente concentrada a lo largo del corredor I-85 entre Charlotte, la Triad y el Research Triangle con otros puntos importantes en Hickory, Wilmington y especialmente Asheville. También parece que los posibles suplidores tienen preferencias de co-localización que se imponen de manera significativa con firmas existentes de energía renovable y eficiencia energética, localizadas en Carolina del Norte. Poco entendimiento existe alrededor de cómo se relacionan entre sí estos potenciales suministradores y empresas de energía renovables y de eficiencia energética con respecto a los efectos de la potencial difusión de conocimiento y la formación de redes formales e informales de producción—un área clave para la investigación futura.

SOUTHEASTERN GEOGRAPHER, 50(1) 2010: pp. 69–88

KEY WORDS: renewable energy, energy efficiency, supply chain, North Carolina, industry clusters

> So we have a choice to make. We can remain one of the world's leading importers of foreign oil, or we can make the investments that would allow us to become the world's leading exporter of renewable energy. We can let climate change continue to go unchecked, or we can help stop it. We can let the jobs of tomorrow be created abroad, or we can create those jobs right here in America and lay the foundation for lasting prosperity.
>
> —*President Obama, March 19, 2009* (The Administration of President Barack Obama, 2009)

INTRODUCTION

The topic of renewable energy frequently takes center stage in conversations about sustainability, climate change, and the conservation of natural resources (Dias et al. 2006; Lund 2007; Kaygusuz 2009). Furthermore, geopolitical concerns about political unrest in many energy resource-rich areas of the world have elevated the need to quickly develop scalable and financially viable renewable energy technologies. More recently, policymakers are increasingly realizing the economic development potential of the renewable energy value chain in terms of generating jobs (Renewable Energy Policy Project (REPP) 2007, 2005, 2004). The employment potential of renewable energy is, in part, due to the potential for renewable energy agglomerations to emerge that can trigger new forms of regional development (Glasmeier and Bell 2006; Cherry and Saha 2008).

In North Carolina, the renewable energy industry is rapidly growing, although it still remains in an incipient stage of development that has yet to fully mature and diversify. As North Carolina begins to diversify and grow its alternative energy industries, a key theoretical and policy question remains as to how should state policymakers stimulate and nurture North Carolina's fledgling renewable energy industry cluster. Industrial clusters are interdependent spatial concentrations of related firms and institutions that are connected by a significant flow of goods and services within a compact geographical area (Porter 1998; Feser and Bergman 2000; Feser and Luger 2003; Porter 2003; Kelton et al. 2008). Location and geographic space have become key factors in explaining the determinants of innovation and technological change (Audretsch and Feldman 1996; Malecki 1997; and Bathelt et al. 2004.) Recently, Ter Wal and Boschma (2009) have suggested that much of this literature has emphasized the importance of localized processes of collective learning based on four different mechanisms of inter-firm knowledge flows. These include: the high level of informal interaction between entrepreneurs; direct interfirm links through various cooperation networks; knowledge spillovers between firms triggered by labor mobility; and, the creation of spin-off firms. Bathelt et al. (2004) have argued that the "buzz" generated by the co-presence and co-location of people and firms within the same value chain can stimulate innovation. Although our understanding of industry cluster dynamics is fairly well developed, it is less clear whether renewable energy and energy efficiency firms and related suppliers co-locate in similar ways to other more established industries. Consequently, this paper should be primarily viewed as a first step in disentangling the co-locational tendencies of the renewable industry and related suppliers rather than a detailed empirical analysis of the explicit dynamics that drive inter-firm networks in the renewable industry.

A good example of a localization economy in North Carolina is the High Point furniture industry cluster where a wide range of furniture designers, marketers and producers have developed a complex web of inter-industry linkages and supply relationships that have nurtured a sustainable competitive advantage. With respect to renewable energy, although much attention has been paid to locating wind turbines in the Appalachian and coastal regions of North Carolina, it is likely that a major portion of the potential benefits will go to the manufacturers that supply the component parts and equipment necessary to build the "new energy" economy. For example, wind turbines have emerged as a major source of demand for fiber-reinforced plastics. Companies like Precision Fabrics in Greensboro, North Carolina, are benefiting from this changing market demand because they now manufacture advanced peel-ply fabrics that are used in building the composite parts found in wind turbines. Given the historically manufacturing-intensive nature of much of the North Carolina economy, and the significant job losses triggered by deindustrialization and the recent recession, it would seem that diversifying into renewables might be a viable employment strategy for some North Carolina manufacturers.

PURPOSE

The purpose of this paper is to better understand the spatial distribution and economic magnitude of North Carolina's renewable energy supply chain in wind, solar, biomass and geothermal by identifying those companies with the technical *potential* to enter the renewable energy market in North Carolina. Rigorously inventorying those firms that could supply the component parts of North Carolina's incipient renewable energy industry could elevate our understanding of the industry cluster theoretic by determining if potential renewable suppliers cluster in similar ways to more conventional industries. It should also be noted that the focus in this paper is on renewable energy as it relates to electricity generation (and not heat generation or transportation fuels such as ethanol and biodiesel).

Secondly, this paper will also identify those firms that are currently providing actual renewable energy and energy efficiency products in North Carolina to establish if these firms have a predisposition to co-locate adjacent to the potential suppliers. Consequently, there are two main types of firms under consideration in this paper: (1) those that have the potential to build the renewable energy supply chain through competencies in related technologies similar to those used to make renewable energy systems and, (2) components *and* firms developing actual renewable and energy efficiency products and innovations. It is hypothesized that renewable energy firms and their potential suppliers are affected by the same localization and urbanization agglomeration economies that shape other more conventional sectors of the economy and that both sets of firms tend to co-locate in similar institutional and competitive settings.

Additionally, it should be noted that although this paper focuses on renewable energy production components (i.e., wind, solar, biomass and geothermal), we have also included in our analysis the fledgling energy-efficiency industry, in part, because the 2009 federal economic stimulus package provided major funding for energy conservation and revived and expanded tax credits for energy-efficient home improvements. However, unlike the renewable energy industry, an established methodology does not currently exist for identifying *potential* energy efficiency suppliers, although the North Carolina Sustainable Energy Association does conduct an annual Economic Census of *actual* energy efficiency firms located in North Carolina.

North Carolina is chosen as the case study because it was the first state in the Southeast to pass a Renewable Energy Portfolio Standard when it was approved by the legislature in 2007. The Portfolio Standard requires public electric utilities in the state to generate at least 12.5 percent of their electricity from renewable energy and energy-efficiency measures by 2021. Additionally, North Carolina is considered one of the most promising locations on the East Coast for wind power (Cherry and Saha 2008)

Little research has been conducted on the spatial distribution of either the potential renewable energy supply chain or the geography of actual renewable energy and energy efficiency firms. Much of the existing literature has tended to focus on both the development of new renewable technological innovations (Jacobsson and Bergek 2004; Cantrell et al. 2008) and the efficacy of various public policy instruments that have been designed to encourage the development of renewable energy markets (Menz 2005; Lewis and Wiser 2007; Wiser et al. 2007). Others such as Smil (2009) have suggested that maintaining the exceptionally high U.S. energy consumption rates is both untenable and highly undesirable. He argues that a far-sighted long-range energy policy should aggressively pursue both substantial efficiency gains and a fundamental reshaping of consumption patterns and a redesign of energy-consuming infrastructures. By contrast, Pasqualetti (2004) is one of the few to have analyzed the spatial distribution of wind power in both the United States and Europe. He also argued that "most countries offer more stable, longer-term policy support for wind than does the United States, and they use mechanisms that are inherently more pluralistic and egalitarian" (Pasqualetti 2004, p 36). This paper attempts to partially remedy this overall dearth in the literature by examining the geography of the renewable energy industry and related suppliers in North Carolina.

PRIOR RESEARCH

Although there has been a lack of research on the geography of renewable energy firms and related suppliers, this paper was particularly influenced by the research conducted by Glasmeier and Bell (2006), Cherry and Saha (2008), REPP (2004, 2005, 2007), and the North Carolina Sustainable Energy Association (NCSEA) (2008). Cherry and Saha (2008) specifically examined renewable energy in North Carolina. They argued that the recently state-approved Renewable Energy Portfolio Standard has the potential to "encourage the growth of a nascent renewable energy industry and its supply chain" (p 12). Cherry and Saha (2008) also pointed out that the North Carolina Portfolio Standard program established "renewable energy certificates" which can be traded separately from the electricity that is generated. A certificate is established when a megawatt hour of renewable energy is created. They argued that certificate transactions can create supplemental revenue streams for owners of renewable energy businesses in North Carolina and also allow suppliers to demonstrate compliance with the Portfolio Standards program by purchasing renewable energy certificates rather than purchasing renewable electricity directly. Cherry and Saha (2008) also suggested that the development of a strong certificate market will encourage the development of a larger renewable energy industry cluster within North Carolina because a real financial incentive now exists for investments made by renewable energy developers. Although Renewable Portfolio Standard programs have now been enacted in more than 20 states, it still remains unclear how the legislation has impacted the geography of the renewable energy industry.

Some of these concerns have been partially rectified by a series of Renewable Energy Policy Project (REPP) reports that were published in the mid-2000's (2004, 2005, 2007) focused on solar, wind, geothermal and biomass energy. REPP (2007, p7–8) found that "nearly 43,000 firms throughout the United States operate in industries related to the manufacturing of components that are needed in renewable energy systems." They argued that the 20 states that would benefit the most from investment in renewable components are largely identical to the 20 states that have lost the most manufacturing jobs in the country in the early 2000s which included North Carolina. Based on a REPP model of a projected U.S. need for 185,000 megawatts of renewable energy, North Carolina was ranked tenth in the nation generating a forecasted 28,544 new jobs and $5.26 billion of investment in manufacturing components to supply this national development of renewables.

One of the few explicitly spatial analyses of both the renewable energy industry and related suppliers was conducted by Glasmeier and Bell (2006), who examined the economic development potential of alternative energy sources in Appalachia. They identified the key renewable and related supplier firms in the Appalachian Regional Commission area from upstate New York to Alabama that produced major manufactured components used in the production of alternative energies, particularly wind power. Based on methodology developed by REPP, Glasmeier and Bell (2006) found that Appalachia is poised to benefit from alternative energy development and that Appalachia has high concentrations of employment in the potential wind and solar energy supply chain industries compared with their relative employment shares nationally.

Although the REPP reports (2004, 2005, 2007) and Glasmeier and Bell (2006) provide some insight into the geography of the renewable energy industry in the aggregate, none of this research was firm-specific. Instead, both REPP and Glasmeier and Bell relied on data aggregated up to the county and state level. The research in this paper is an attempt to elevate our understanding of North Carolina's fledgling

Table 1. Listing of Organizations Contacted for the NCSEA Industry Census of North Carolina Renewable and Energy Efficiency Firms, 2008

NCSEA Business Members Database
American Wind Energy Association Member Directory
Appalachian State University Energy Center Manufacturers List
EPA Energy Star Business Partners
FindSolar.com Online Directory
Green Home Builders of the Triangle Member Directory
NC Healthy Built Homes Member Directory
North Carolina Solar Center Directory of Renewable Energy Professionals
Residential Energy Services Network (RESNET) Certified Raters Directory
Small Business Innovation Research Recipients List
Source Guide Renewable Energy Businesses
US Green Building Council Member Directory
Western North Carolina Green Building Council Business Members List

Source: NCSEA 2008

renewable industry cluster by developing an improved firm-specific understanding of the spatial distribution of renewable suppliers and firms.

One of the only firm-specific analyses of renewable energy in North Carolina was provided by NCSEA (2008), although their key findings were presented in the aggregate to protect the confidentiality of participating firms. NCSEA identified 486 firms that comprised the renewable energy and energy efficiency industry in North Carolina based on their analysis of the member directories of the various organizations (Table 1). From this master list of firms, a total of 166 companies responded to the 2008 NCSEA Industry Census. NCSEA found that manufacturing formed an important component of the renewable energy and energy efficiency industry in North Carolina accounting for more than 70 percent of the reported jobs. They also found that most of the manufacturing firms in North Carolina produced components, rather than end units, for the renewable energy and energy-efficiency industry and that significant industry clusters were apparent in the Research Triangle, Charlotte and Asheville regions.

METHODOLOGY

To further assess the spatial distribution and economic magnitude of the "new energy economy" supply chain in North Carolina, this paper partly utilized the methodology developed by REPP (2004, 2005, 2007). REPP developed a methodology that disaggregated renewable generation technologies into their individual component parts and then catalogued where existing conventional industries are located that could become potential suppliers to this "new energy economy." In order to examine the spatial distribution and magnitude of this *potential* market, REPP utilized an approach based on the North American Industrial Classification

System (NAICS) utilized by the Federal Government to identify firms in similar production processes. REPP identified all the 6-digit NAICS codes that might include firms involved in activities similar to the manufacturing of the individual renewable energy components found in wind, solar, biomass or geothermal production. For example, REPP argued that a company that makes glass plate (i.e., NAICS 327211 Flat Glass Manufacturing) could potentially transfer its capabilities to making the top surface glass for photovoltaic solar modules. The NAICS codes identified by REPP that are included in this paper are listed in Table 2. Additionally, some of the more detailed NAICS-based analysis of the North Carolina renewable energy supply chain is provided in Debbage (2008).

One caveat to this overall approach is that some of the selected NAICS codes include a broad range of products, some of which are not wholly related to renewable energy production. Additionally, it is important to recognize that some of the NAICS-defined industries listed in Table 2 can be potential suppliers for more than one renewable. For example, both geothermal and biomass require similar inputs and therefore include some of the same NAICS-defined industrial suppliers. Consequently, it is inappropriate to aggregate firm or employment data across the four major classes of renewables since this can inflate the economic data due to potential double counting.

Identifying the various industry specializations necessary to sustain a potential "new energy economy" supply chain is one matter. Cataloguing and mapping the specific firms that might be part of a successful supply chain is a completely different task. The 2008 data source for the North Carolina inventory of the potential renewable energy suppliers was *ReferenceUSA*. The *ReferenceUSA* database contains detailed information on more than 14 million U.S. businesses. Information is compiled from the following public sources: more than 5,600 Yellow Page and Business White Page telephone directories; annual reports; 10-Ks and other SEC information; federal, state, and municipal government data; Chamber of Commerce information; leading business magazines, trade publications, newsletters, major newspapers, industry and specialty directories; and postal service information. Businesses with 100 or more employees are phone-verified at least twice a year and the database is continually updated. *ReferenceUSA* is an excellent database for mapping specific firms since it provides a precise map coordinate location for all listed companies by NAICS code. The data utilized to build the North Carolina renewable energy supply chain inventory were accessed in summer 2008. Only those firms listed under the NAICS codes identified by the REPP methodology were included in the inventory. It should be noted that some company data are not fully reported in *ReferenceUSA* for reasons of confidentiality. For example, some companies report data ranges rather than precise figures for employment, sales volume, and floor space.

Along with the *potential* renewable supplier, an additional database of the *actual* renewable energy- and energy-efficiency firms currently operating in North Carolina was mapped based on a sample of the 486 firms identified in the 2008 NCSEA Census. Because the data are proprietary and business confidential, a confidentiality

Table 2. Potential Renewable Energy Suppliers based on NAICS Defined Industries

NAICS Code	NAICS Description
A. Wind	
326199	All Other Plastics Products
331511	Iron Foundries
332312	Fabricated Structural Metal
332991	Ball & Roller Bearing
333412	Industrial & Commercial Fans and Blowers
333611	Turbine and Turbine Generator Set Units
333612	Speed Changer, Drive & Gear
333613	Mechanical Power Transmission Equipment
334418	Printed Circuits & Electronics Assemblies
334519	Measuring & Controlling Devices
335312	Motors & Generators
335999	Electronic Equipment & Components, Misc.
B. Solar	
325211	Plastics Material & Resin
326113	Unlaminated Plastics Film & Sheet (except Packaging)
327211	Flat Glass
331422	Copper Wire (except Mechanical) Drawing
332322	Sheet Metal Work
334413	Semiconductors & Related Devices
334515	Instruments for Measuring & Testing Electricity & Electrical Signals
335313	Switchgear & Switchboard Apparatus
335911	Storage Batteries
335931	Current-Carrying Wiring Devices
335999	Electronic Equipment and Components, Misc.
C. Biomass	
327993	Mineral Wool
331210	Iron, Steel Pipe & Tube from Purchased Steel
332410	Power Boiler & Heat Exchanger
332420	Metal Tank (Heavy Gauge)
332911	Industrial Valve
333120	Construction Machinery
333210	Sawmill & Woodworking Machinery
333411	Air Purification Equipment
333414	Heating Equipment (except Warm Air Furnaces)
333415	AC and Warm Air Heating Equipment and Commercial and Industrial Refrigeration Equipment Manufacturing
333911	Pump & Equipment
333912	Air & Gas Compressor

Table 2. Continued

NAICS Code	NAICS Description
C. Biomass *Continued*	
333922	Conveyor & Conveying Equipment
333923	Overhead Traveling Crane, Hoist & Monorail System
333999	General Purpose Machinery, Misc.
334513	Instruments and Related Products for Measuring, Displaying, and Controlling Industrial Process Variables
335311	Power, Distribution, and Specialty Transformer
335999	Electronic Equipment & Components, Misc.
336510	Railroad Rolling Stock
D. Geothermal	
331210	Iron, Steel Pipe & Tube from Purchased Steel
332410	Power Boiler & Heat Exchanger
332420	Metal Tank (Heavy Gauge)
333415	AC and Warm Air Heating Equipment and Commercial and Industrial Refrigeration Equipment Manufacturing
333911	Pump & Pumping Equipment
333912	Air & Gas Compressor
333923	Overhead Traveling Crane, Hoist & Monorail System

Source: REPP (2004, 2005, 2007)

agreement was signed with NCSEA that prohibited disclosing the identity of specific firms. The firms included in the NCSEA Census met at least one of the following criteria: at least 50 percent of staff time or revenue was dedicated to work related to renewable energy or energy efficiency and/or at least $25,000 in revenue came from work in renewable energy or energy efficiency. Consequently, the NCSEA Census included firms specializing in renewable energy and energy efficiency as well as more diversified, larger firms that are significant to the industry. NCSEA defined renewable energy firms as those involved in development, design, engineering, financing, manufacturing, installing or the maintenance of renewable energy systems and components. By contrast, energy efficiency firms were defined as those that develop, manufacture, or install systems that cut energy waste such as energy-efficient homes and buildings, LED lighting, building controls, and efficient appliances.

FINDINGS

North Carolina's *potential* new energy economy supply chain is a diverse and mature sector of the state economy comprising just over 1,300 firms and employing just over 61,000 workers (note: these figures are aggregate totals after subtracting out those NAICS-defined industries that were listed for more than one renewable).

Table 3. North Carolina's Potential Supply Chain, 2008

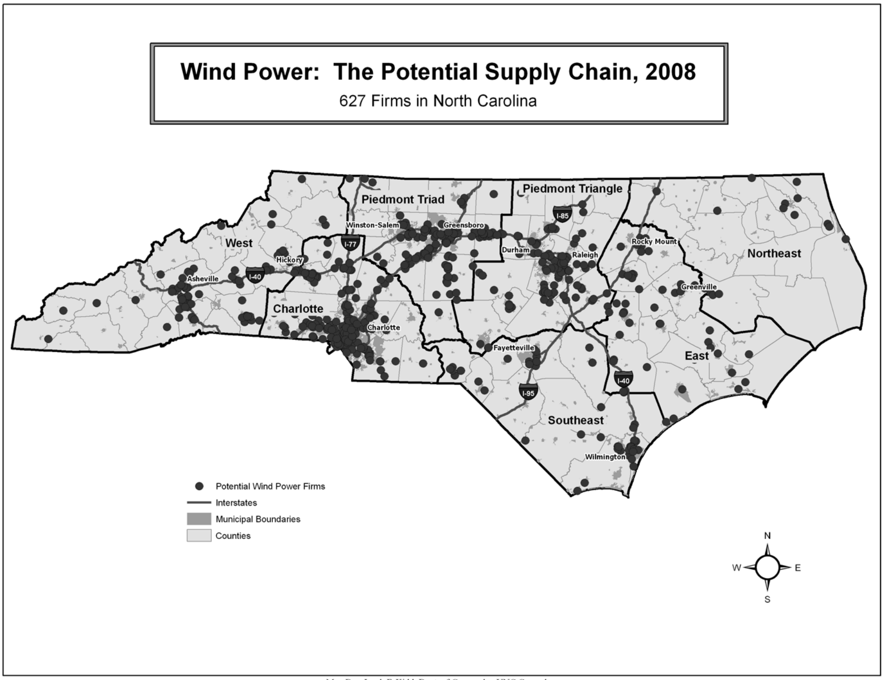
Renewable	Number of Firms[1]	Employment[1]
Wind	627	32,534
Solar	296	16,122
Biomass	508	20,925
Geothermal	98	4,287

[1]It is inappropriate to aggregate these data since some firms are listed for more than one of the renewables.

The largest potential supply chain in North Carolina appeared to be wind-energy related since it generated the largest number of firms (627) and jobs (32,534) relative to the other three forms of renewable energy (Table 3). Given the long history of manufacturing in the North Carolina economy, it is not surprising that some of the leading sectors of the new energy supply chain economy are manufacturing intensive (Table 4). These potential suppliers included firms specializing in various types of plastic product manufacturing (230 firms and 14,710 jobs), fabricated structural metal manufacturing (186 firms and 4,611 jobs), sheet metal work manufacturing (84 firms and 3,487 jobs), as well as semiconductor and related device manufacturing (45 firms and 2,271 jobs). The semiconductor manufacturers are a good example of a key supplier since they can play a substantive role in facilitating the production of photovoltaic cells. Current solar cell technology consist primarily of a semiconductor material in which photons are absorbed from the incoming light to create free electrons. We now turn to a more detailed examination of the potential suppliers of each type of renewable energy, although we do not analyze the potential

Table 4. North Carolina's Leading Supply Chain Industries, 2008

Renewable	# of Firms	Employment
Wind		
• All Other Plastics Product Manufacturing	230	14,710
• Fabricated Structural Metal Manufacturing	186	4,611
• Ball and Roller Bearing Manufacturing	14	2,019
Solar		
• Sheet Metal Work Manufacturing	84	3,487
• Plastic Material and Resin Manufacturing	62	2,876
• Semiconductor and Related Devices	45	2,271
Biomass/Geothermal		
• General Purpose Machinery, Misc.	148	3,935
• Pumps and Pumping Equipment	24	2,032
All Renewables		
• Electrical Equipment, Misc.	61	4,254



Map By: Jacob F. Kidd, Dept. of Geography, UNC Greensboro

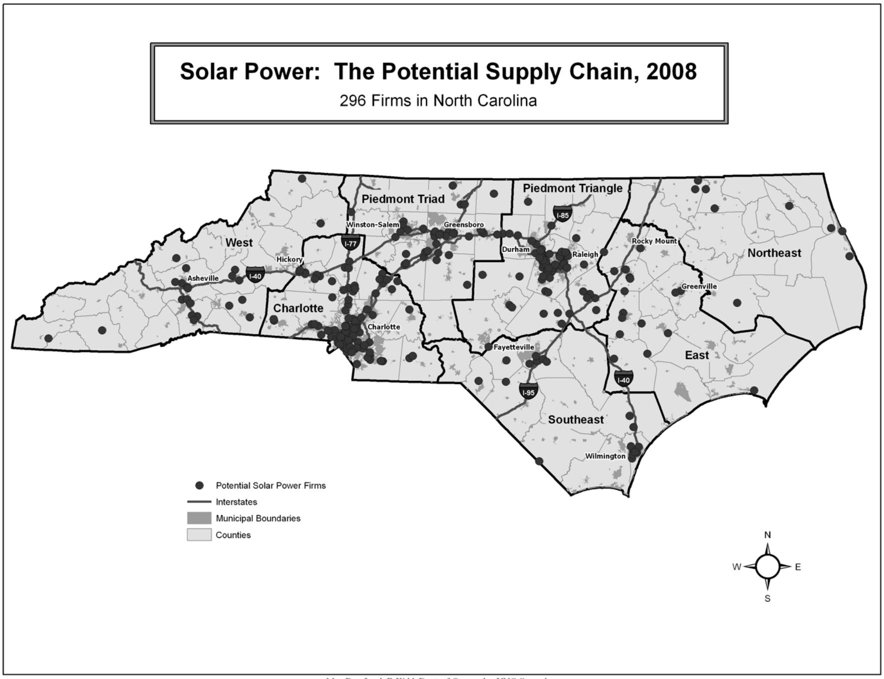
Figure 1. Spatial Distribution of Potential Wind Energy Suppliers in North Carolina, 2008.

geothermal suppliers given the limited role such companies play in the North Carolina economy (Table 3).

Potential Wind Power Suppliers

For wind power, this paper analyzed the potential supply chain that could provide the component parts needed to construct a utility scale wind turbine for electricity generation typically larger than 1MW capacity. Although the statewide geography of the potential wind energy supply chain is more widely distributed than for solar energy (Figure 1 and 2), an important cluster of wind energy related suppliers exists in the highly diversified Charlotte region. The regions used in this report are defined based on the North Carolina Department of Commerce economic development regions. In 2008, the Charlotte region had 195 firms that could potentially play a role in the wind energy-supply chain (Table 5) and these firms generated 12,770 jobs in the region (Table 6). Many of these jobs were concentrated in just a few specialties including various forms of plastic product manufacturing, fabricated structural metal manufacturing, electrical equipment manufacturing and ball and roller bearing manufacturing.

Given the manufacturing orientation of the Piedmont Triad region, it is perhaps not surprising that the Triad region generated more jobs in potential wind energy



Map By: Jacob F. Kidd, Dept. of Geography, UNC Greensboro

Figure 2. Spatial Distribution of Potential Solar Energy Suppliers in North Carolina, 2008.

supply chain-related industries than the Research Triangle (6,520 and 4,099, respectively) (Table 6). The Piedmont Triad also generated more firms (133) than the Research Triangle (101) (Table 5). Another region that featured prominently was the West region which included Asheville. It is perhaps expected that a substantive cluster of wind energy-related industries might thrive in the Asheville area especially given the high winds associated with its mountainous topography. Asheville is already a region noted for its "green collar" economy (*Asheville Times* 2008) and the area already appears to have generated a disproportionately large cluster of industries linked to potential wind energy applications. Overall, the West region generated more jobs (4,770) than the Re— search Triangle region (4,099) in this niche (Table 6).

North Carolina's potential wind suppliers are characterized by a preponderance of firms with sales volume between $1–5 million (258 firms or 41.7 percent of total sales). Only one firm generated between $500 million to $1 billion in sales and that was Siemens Power Generation in Charlotte with 799 workers. Most of the potential wind energy suppliers are also fairly small in terms of floor-space with 440 firms (70.2 percent) below 40,000 square feet in size. The preponderance of small-sized firms suggests that complex webs of inter-industry linkages may proliferate between various suppliers and the actual renewable energy industry in the future if the industry continues to grow.

Table 5. Number of Potential Renewable Energy Supplier Firms by Region, 2008

	NC Department of Commerce Region							
Renewable	West	Charlotte	Piedmont Triad	Research Triangle	South-east	East	North-east	Total
Wind	81	195	133	101	49	53	15	627
Solar	22	109	38	83	18	17	9	296
Biomass	42	181	97	101	41	32	11	509

Table 6. Potential Renewable Energy Supplier Employment by Region, 2008

	NC Department of Commerce Region							
Renewable	West	Charlotte	Piedmont Triad	Research Triangle	South-east	East	North-east	Total
Wind	4770	12770	6520	4099	1914	2115	342	32534
Solar	879	5011	3876	3538	1504	929	385	16122
Biomass	2748	4857	4943	5334	1773	772	498	20925

Potential Solar Power Suppliers

Given the focus on renewable electricity generation in this paper, the potential solar power suppliers include only those able to provide component parts necessary to manufacture solar photovoltaics. That said, the statewide geography of potential solar energy suppliers is noticeably different from that of wind energy. Given the technological propensities of solar energy suppliers (e.g., semiconductors and related devices manufacturing), this potential supply chain does not proliferate across North Carolina. A much more pronounced and tightly circumscribed cluster of industries exists in both the Charlotte and the Research Triangle markets (Figure 2) while the West region did not feature as prominently, especially when compared to wind energy (Figure 1). The potential solar energy-related suppliers seem to prefer the more highly skilled labor pools in Charlotte and Raleigh-Durham.

In 2008, the Charlotte region included 109 potential suppliers to the solar energy industry (Table 5) and these suppliers generated 5,011 jobs (Table 6)—far more than any other region in North Carolina. Other important regions included the Research Triangle region (i.e., 83 firms and 3,538 jobs) and the Piedmont Triad (i.e., 38 firms and 3,876 jobs). These three regions generated 77 percent of all the jobs in North Carolina's potential solar energy supply chain—compared to a 72 percent market share for wind energy. It should also be noted that the Piedmont Triad may have generated fewer firms than the Research Triangle region but it did produce more jobs, suggesting that average firm size is larger in the Triad.

North Carolina's potential solar power suppliers featured a disproportionate number of firms with sales volume between $1–10 million (172 firms or 61.3 percent of total sales). Unlike the wind-related firms, a larger proportion of solar-related firms generated between $5–$10 million in sales (24.8 percent versus 14.1 percent), and one firm generated over $1 billion in sales (i.e., Goodrich Corporation in Charlotte). Of course, companies like Goodrich and Siemens are qualitatively, as well as quantitatively, different from a small machine shop given the global reach of their respective supply chains. That said, most of the potential solar energy-related suppliers were fairly small in terms of floor-space, with 53.7 percent of all firms between 10,000 and 39,999 square feet in size. However, a significant proportion of firms were larger than 40,000 square feet (111 firms or 37.5 percent of the total), especially when compared to the equivalent proportion of wind energy-related firms (29.8 percent).

Potential Biomass Suppliers

For biomass power generation, this paper analyzed the potential supply chain that could provide the component parts needed to construct a dedicated biomass plant. In such a plant, the biomass is burned in a boiler to generate steam that is then passed through a steam turbine-generator. (The biomass data are only for direct combustion equipment since they are the only technology widely ready for commercialization. They do not include biotech-oriented technology such as gasification or bio-fuels).

The geography of the potential biomass supply chain is tightly concentrated along the I-85 corridor between Charlotte, the Triad and the Research Triangle region, with significant outposts in Asheville, Hickory and Wilmington (Figure 3). Approximately 75 percent of the potential biomass supply chain in North Carolina is located in one of three regions—Charlotte (181 firms), the Research Triangle (101) and the Piedmont Triad (97) (Table 5). Significant specializations include general purpose machinery manufacturing (148 firms), electrical equipment (61), sawmill and woodworking machinery (49) and construction machinery manufacturing (41). These four specializations accounted for nearly 60 percent of the potential statewide supply chain in biomass.

In employment terms, the largest potential biomass supply chain labor market was in the Research Triangle region (5,334 workers) and not Charlotte (4,857) (Table 6), even though Charlotte generated more firms (Table 5). Additionally, both the West (2,748) and the Southeast regions (1,773) are well represented in employment terms even though both regions have only a modest number of total firms (42 and 32, respectively).

Over one-quarter (130 firms) of the potential biomass suppliers generated between $1 million and $2.5 million in sales in 2008. Overall, sales figures lagged behind those for the potential wind and solar suppliers. Nearly half of the biomass suppliers generated less than $2.5 million in sales compared to 41.7 percent for wind power companies and 30.4 percent for solar power. Furthermore, no biomass supplier generated more than $500 million in sales. In terms of floor space, most of the biomass supply-chain firms were between 10,000–39,999 square feet in size (297

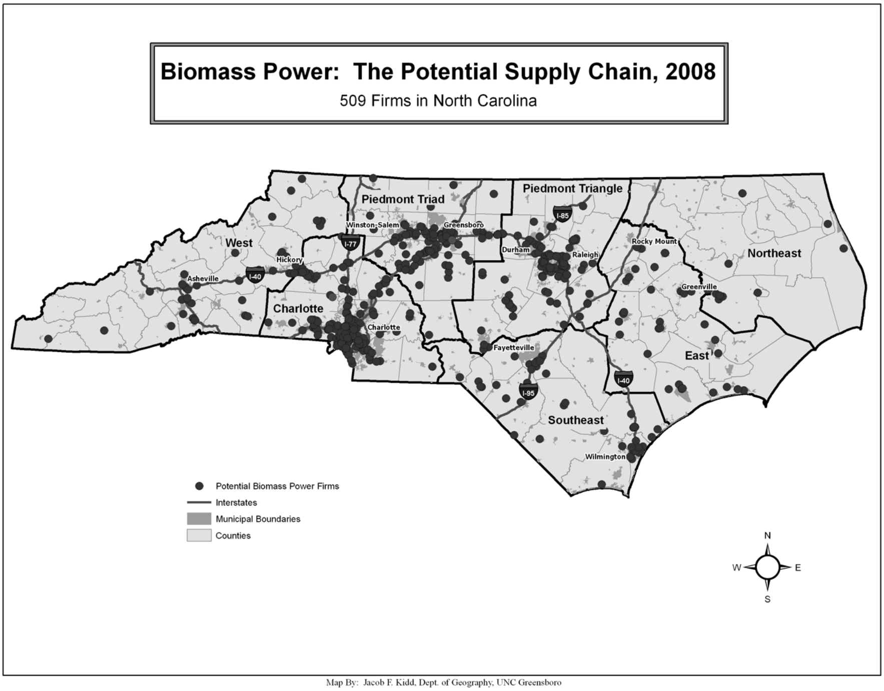


Figure 3. Spatial Distribution of Potential Biomass Energy Suppliers in North Carolina, 2008.

companies or 58.5 percent of the total). The biomass firms had a larger share of smaller firms (20.9 percent) and fewer large firms (20.7 percent) than their wind or solar energy supply counterparts.

Theoretical Implications

Given the diversity and small size of many of the potential renewable suppliers in terms of employment generation and floor-space needs, it is possible that North Carolina's emerging renewable energy value chain will include a complex and highly heterogeneous web of inter-industry linkages. These fledgling relationships are likely to be nurtured by various knowledge spillovers that are based on relationships that are already embedded in the renewable industry cluster through the evolution of localized and tacit knowledge sources that are accessible only to those within this highly specialized cluster (Bathelt *et al*. 2004; Ter Wal and Boschma 2009). It remains less clear what specific aspects of the renewable energy industry in North Carolina can lead to the kind of innovation that industry clusters are known to induce. One key avenue of future research might be to conduct a more qualitative analysis that conveys the actual substance of the sorts of inter-firm relationships that are critical in terms of triggering more innovative products (e.g., information sharing, the building of trust and social capital between functionally related suppliers, etc). We now turn to an

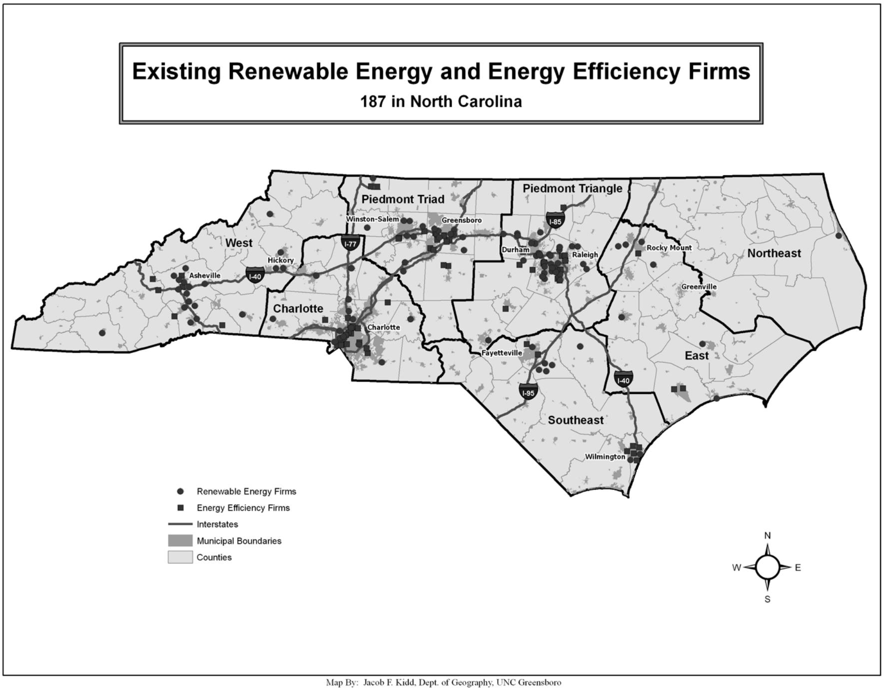


Figure 4. Spatial Distribution of Existing Renewable Energy and Energy Efficiency Firms in North Carolina, 2008.

examination of the spatial distribution of the actual renewable energy and energy efficiency industry in North Carolina to establish whether or not it broadly corresponds with the geography of the potential suppliers.

Existing Renewable Energy and Energy Efficiency Firms in North Carolina

Based on the master-list of 486 firms identified by NCSEA (2008), we identified 121 renewable energy firms and 66 energy efficiency firms that appeared to have either a strong core business in either renewable energy or energy-efficiency or were larger firms that had developed a substantive secondary interest in renewable energy applications and/or energy-efficiency innovations. These 187 firms were targeted based on both an analysis of company websites and through an analysis of additional company data accessed through the *ReferenceUSA* database. We excluded several builders, contractors and architect practices from the master list that seemed to have negligible renewable and/or energy efficiency interests. Consequently, the database reported in this paper differs slightly from that reported for the 166 firms that responded to the NCSEA Census.

Although renewable energy and energy efficiency firms are located across the state (Figure 4), it appeared that a significant cluster of renewable energy firms

Table 7. Number of Renewable Energy and Energy Efficiency Firms by Region, 2008

	NC Department of Commerce Region							
Firm Type	West	Charlotte	Piedmont Triad	Research Triangle	South-east	East	North-east	Total
Renewable Energy	20	21	19	45	8	7	1	121
Energy Efficiency	6	16	15	19	7	3	0	66

Table 8. Renewable Energy and Energy Efficiency Employment by Region, 2008

	NC Department of Commerce Region							
Firm Type	West	Charlotte	Piedmont Triad	Research Triangle	South-east	East	North-east	Total
Renewable Energy	782	6,749	2,614	3,281	1,461	375	4	15,264
Energy Efficiency	96	834	576	501	84	34	0	2,124

existed in the Research Triangle region (45 firms or 37.2 percent of the total) and many of these were engaged in solar energy applications (Table 7). By contrast, the geography of energy-efficiency firms was more evenly distributed and lacked the pronounced firm clusters evident in the renewable-energy industry. In terms of employment generation, the renewable energy industry generated 15,264 jobs compared to just 2,124 jobs in the energy-efficiency industry (Table 8), although this may be overstated since much of this was attributable to a small number of very large Charlotte-based firms with significant secondary interests in renewable energy. As a consequence of this, the Charlotte region generated a disproportionate share of jobs in the renewable energy and energy-efficiency industries collectively (7,583 jobs or 43.6 percent of the total) even though more firms were operating in the Research Triangle region.

Although the geography of the renewable energy and energy-efficiency industry in North Carolina appears to be subtly different from the potential renewable suppliers, a Spearman's Rank Correlation Coefficient was calculated by aggregating the firm data to the county level to provide a more quantifiable assessment of the level of spatial association between the two variables. Based on the employment data, it appears that the 121 renewable energy firms are positively correlated at the one percent level of significance with the potential suppliers for wind energy applications (correlation score of $R=0.47$), solar energy ($R=0.40$) and biomass ($R=0.52$). By contrast, the correlation scores for energy efficiency firm employment by county were slightly lower although they were also positively correlated at the one percent level of significance (e.g., wind $R=0.43$; solar $R=0.37$; and biomass $R=0.39$). It is perhaps not surprising that the renewable energy industry in North Carolina more closely approximates the geography of potential renewable suppliers (i.e., higher correlation scores) since the energy-efficiency industry may have very different supplier needs when compared to wind, solar and biomass energy-supply needs. Overall, it appeared as if both the potential suppliers of renewable energy components and the actual practitioners favored comparable urbanization and localization economies. If an agglomeration of related suppliers tends to increase rates of innovation and productivity as suggested in the literature (Audretsch and Feldman 1996; Malecki 1997), then perhaps we should expect a competitive renewable energy industry to behave no differently to successful conventional industries regarding their locational preferences.

CONCLUSION

The integration of new energy technology development and North Carolina's existing strengths in manufacturing production has the potential to place the state at the forefront of renewable energy development. Although North Carolina has yet to develop a mature and diversified new energy economy, the state is home to over 1,300 companies and 61,000 workers that operate within the potential renewable energy supply chain. Furthermore, the geography of the potential suppliers is tightly concentrated along the I-85 corridor between Charlotte, the Triad and the Research Triangle region with significant outposts in Hickory, Wilmington and especially Asheville.

Improved understanding of the spatial distribution of the potential manufacturers that could supply renewable energy firms with critical component parts can help complete our understanding of theories of industry clusters and help economic development practitioners to craft appropriate policies and incentives that allow innovative renewable energy companies to flourish. It also appears that the potential suppliers overlap significantly in terms of locational preferences with the actual renewable energy and energy-efficiency firms already located in North Carolina. Less well understood is how these potential suppliers and renewable/energy-efficiency firms inter-relate regarding both potential knowledge spillover effects and the formation of formal and informal networks of production—a key area for future research.

REFERENCES

Asheville Times. 2008. *Could Asheville become a hub for green economy?* May 18.

Audretsch, D.B., and Feldman, M.P. 1996. Innovative Clusters and the Industry Life Cycle. *Review of Industrial Organisation* 11:253–273.

Bathelt, H., Malmberg, A., and Maskell, P. 2004. Clusters and Knowledge: Local Buzz, Global Pipelines and the Process of Knowledge Creation. *Progress in Human Geography* 28(1):31–56.

Cantrell, K., Ducey, T., Ro, K., and Hunt, P. 2008. Livestock waste-to-bioenergy generation opportunities. *Bioresource Technology* 99:7941–7953.

Cherry, D., and Saha, S. 2008. Renewable Energy in North Carolina *Popular Government* Spring/Summer:12–23.

Debbage, K.G. 2008. *Renewable Energy in North Carolina: The Potential Supply Chain.* Institute for Emerging Issues: Raleigh.

Dias, R., Mattos, C., and Balestieri, J. 2006. The limits of human development and the use of energy and natural resources. *Energy Policy* 34(9):1026–1031.

Feser, E.J., and Bergman, E.M. 2000. National Industry Cluster Templates: A Framework for Applied Regional Cluster Analysis. *Regional Studies* 34(1):1–19.

——, and Luger, M.I. 2003. Cluster Analysis as a Mode of Inquiry: Its Use in Science and Technology Policymaking in North Carolina. *European Planning Studies* 11(1):11–24.

Glasmeier, A., and Bell, T. 2006. *Economic Development Potential Of Conventional And Potential Alternative Energy Sources In Appalachian Counties.* Appalachian Regional Commission: Chattanooga.

Jacobsson, S., and Bergek, A. 2004. Transforming the energy sector: the evolution of technological systems in renewable energy technology. *Industrial and Corporate Change* 13(5):815–849.

Kaygusuz, K. 2009. Wind Power for a Clean and Sustainable Energy Future. *Energy Sources Part B: Economics, Planning & Policy* 4(1):122–133.

Kelton, M.L., Pasquale, M.K., and Rebelein, R.P. 2008. Using the North American Industrial Classification System (NAICS) to Identify National Industry Cluster Templates for Applied Regional Analysis. *Regional Studies* 42(3):305–321.

Lewis, J., and Wiser, R. 2007. Fostering a renewable energy technology industry: An international comparison of wind industry policy support mechanisms. Energy Policy 35: 1844–1857.

Lund, H. 2007. Renewable energy strategies for sustainable development. *Energy* 32:912–919.

Malecki, E.J. 1997. *Technology and Economic Development: The Dynamics of Local, Regional and National Competitiveness.* Addison Wesley Longman: London.

Menz, F. 2005. Green electricity policies in the United States: case study. *Energy Policy* 33: 2398–2410.

North Carolina Sustainable Energy Association. 2008. *North Carolina Renewable Energy and Energy Efficiency Industry Census 2008*. NCSEA: Raleigh.

Pasqualetti, M.J. 2004. Wind Power: Obstacles and Opportunities. *Environment* 46(7):23–38.

Porter, M. 1998. Clusters and the New Economics of Competition. *Harvard Business Review* November-December:77–90.

——. 2003. The Economic Performance of Regions. *Regional Studies* 37(6/7):549–578.

Renewable Energy Policy Project. 2007. *Component Manufacturing: Massachusetts's Future in the Renewable Energy Industry.* REPP Technical Report: Washington DC.

——. 2005. *Solar PV Development: Location of Economic Activity.* REPP Technical Report: Washington DC.

——. 2004. *Wind Turbine Development: Location of Manufacturing Activity.* REPP Technical Report: Washington DC.

Smil, V. 2009. U.S. Energy Policy: The Need for Radical Departures. *Issues in Science and Technology.* Summer:47–50.

Ter Wal, A.L.J., and Boschma, R.A. 2009. Co-evolution of Firms, Industries and Networks in Space 2009. *Regional Studies,* in press, available on-line as i-First paper.

The Administration of President Barack Obama. 2009. The Agenda, Energy and the Environment, White House website. Accessed 26 January 2009 at http://www.whitehouse.gov/agenda/energy_and_environment/.

Wiser, R., Namovicz, C., Gielecki, M., and Smith, R. 2007. The Experience with Renewable Portfolio Standards in the United States. *The Electricity Journal* 20(4):8–20.

KEITH G. DEBBAGE is a Professor in the Department of Geography, University of North Carolina at Greensboro, Greensboro, NC 27402. Email: kgdebbag@uncg.edu. His research interests include urban and economic development, tourism and the airline industry. JACOB KIDD is a Master of Arts student in the Department of Geography, University of North Carolina at Greensboro, Greensboro, NC 27402. Email: jfkidd@uncg.edu. His research interests include economic development and renewable energy.