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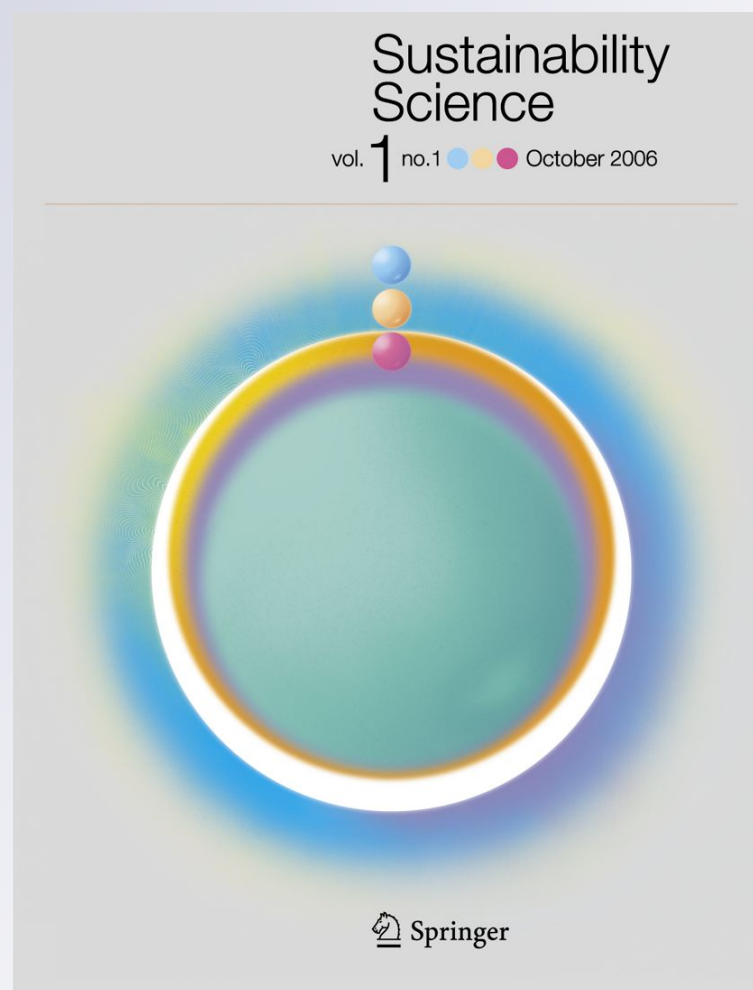
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Green energy clusters and socio-technical transitions: analysis of a sustainable energy cluster for regional economic development in Central Massachusetts, USA

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Abstract As the societal benefits associated with transitioning to more sustainable, less fossil fuel-reliant energy systems are increasingly recognized by communities throughout the world, the potential of creating ‘green jobs’ within a ‘green economy’ is attracting much attention. Green energy clusters are increasingly promoted throughout the world as a strategy to simultaneously promote economic vitality and stimulate a sustainable energy transition. In spite of their emerging role in regional-scale sustainability planning efforts, such initiatives have not been considered within the sustainability transitions literature. This paper explores the development of one such regional sustainable energy cluster initiative in Central Massachusetts in Northeastern USA to consider the potential for such cluster initiatives to contribute to socio-technical transition in the energy system. Since 2008, a diverse set of stakeholders in Central Massachusetts, including politicians, universities, businesses, local citizens, and activists, have been working toward facilitating the emergence of an integrated cluster of activity focused on sustainable energy. Through interviews with key actors, participant observation, and document review, this research assesses the potential of this cluster initiative to contribute

to a regional socio-technical transition. The empirical details of this case demonstrate that sustainable energy cluster initiatives can potentially accelerate change in entrenched energy regimes by promoting institutional thickness, generating regional ‘buzz’ around sustainable energy activities, and building trust between multiple and diverse stakeholders in the region. This research also contributes to emerging efforts to better ground socio-technical transitions in geographic space.

Keywords Clusters · Energy systems · Green energy · Socio-technical transitions · Niche · Energy innovation

Introduction

The challenges of meeting the basic needs of humanity are mounting, as climate instability caused primarily from reliance on fossil fuel-based energy systems is coupled with global economic uncertainty (Engleman 2009; Brown 2011). As localities throughout the world seek to address this dual challenge, the potential of creating ‘green jobs’ within a ‘green economy’ has increasing appeal (Vaitheswaran 2003; Jones 2008). Some communities have been pursuing this aspiration through regional green cluster initiatives aimed at promoting the growth of a local sustainable energy sector in order to facilitate a transition to a more sustainable green energy economy. This coupling of the classic regional economic development tool of geographic clustering of related industrial activity (Krugman 1995; Amin 1999; Porter 2000) with the rapidly emerging efforts to transition to more sustainable energy systems (Loorbach 2007) results in a politically compelling approach to simultaneously advance multiple societal goals. While the merging of these two notions is occurring

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in practice, consideration of the role of such regional economic development initiatives in scholarship on sustainability transitions has been minimal.

Theoretical perspectives on sustainability transitions have been guided most significantly by work on socio-technical transitions, which evolved from studies of technology innovation and diffusion, evolutionary economics, and the sociology of large technical systems to provide a framework for understanding how shifts in large and complex socio-technical systems unfold (Rotmans et al. 2001; Brown et al. 2004; Loorbach 2007; Geels 2010; Smith et al. 2010). The predominant model of transition dynamics, the multi-level perspective (MLP), articulates that, for a socio-technical transition to occur, an entrenched, mainstream regime (e.g., the fossil fuel-based energy system) must experience synergistic pressures from three different levels (Geels 2005a, b; Genus and Coles 2008). The landscape level refers to the broader socio-technical context shaped by demographic structures, the natural environment, broad social values, culture, worldviews, and the macro political economy; the regime level refers to the entrenched regime itself, with its configuration of existing technologies, practices, rules, and shared assumptions; and the niche level is where experimentation with innovative ideas and technologies takes place, allowing alternatives to mature and possibly compete at the regime level (Rip and Kemp 1998; Geels 2002).

The socio-technical transitions framework was developed largely on the basis of the historical analysis of past transitions. As the framework is increasingly utilized to inform and guide emerging transitions toward sustainability, transition studies are confronting the broader and more complex range of factors that facilitate or constrain socio-technical change as they unfold, through fits and starts, in particular places and across geographic scales. The transformation of complex socio-technical systems, and particularly the shift from a fossil fuel-based energy system to one reliant on renewable energy sources, involves a significant re-shaping of regional, place-based infrastructures, economic systems, and social practices. While the literature on socio-technical transitions has been influential in highlighting the co-evolution of technologies, culture, and other social factors, the framework remains centrally focused on describing the trajectory of technological change, without sufficient consideration of the ways in which transitions are embedded in local regions and, indeed, re-make those regions (Smith et al. 2010). Considerations of space and the benefits of geographic proximity have been integrated into some recent work on socio-technical transitions (Truffer 2008; Coenen et al. 2010; Späth and Rohrer 2010; Truffer and Coenen 2012), yet, there remains a need to further understand sustainability transitions as regional transformations. Doing so turns

attention toward the social dynamics of regional actors and institutions which are critical to advancing socio-technical change on the ground, but which have not been well-considered in the literature on socio-technical transitions.

Socio-technical transition studies have emphasized the key role of novel, niche technologies in destabilizing and displacing entrenched regimes. In order for niche technologies to diffuse beyond transition experiments or demonstration projects and achieve wider uptake across a region, however, policy and planning initiatives at the regional level must support the socio-technical change. Regional economic development strategies are central drivers of regional change and transformation—involving infrastructural development, economic stimulus, and job creation—and, therefore, they can be expected to play a critical role in implementing niche technologies at the regional scale and promoting sustainability transitions.

As green energy clusters, or cleantech clusters, are increasingly pursued by localities around the world seeking to establish sustainable energy economies, it is important to consider the implications of these initiatives for achieving a widespread sustainable energy transition. Are such initiatives likely to support a sustainability transition? What complications are raised by the use of mainstream economic development tools for achieving energy sustainability? And how do such initiatives interface with other transition strategies? Addressing these issues provides insight into an increasingly important dynamic in energy policy and climate change response strategies at the regional level. Furthermore, by examining the role played by regional economic development initiatives, it advances socio-technical transitions frameworks by incorporating considerations of regional policy, economic development, and the re-making of regions.

One focused regional initiative to promote a sustainable energy cluster and associated green jobs has been developing in Central Massachusetts in Northeastern USA, where a diverse set of stakeholders, including politicians, universities, businesses, local citizens, and activists, have embarked on an integrated effort to promote a geographic cluster of activity focused on sustainable energy (D'Amico 2007; Kennedy 2009). The city of Worcester, the largest city in the region, is the geographic focal point for this initiative. As a former industrial city seeking to transform from an industrial manufacturing, 'smokestack' economy to a cleaner, knowledge-based economy, Worcester typifies the experience of older cities throughout the developed world, and it exemplifies the coupled challenge of economic restructuring and energy system transformation. The city is the site of a successful biotech cluster initiative which has stimulated a local knowledge-based economy, provided a model of successful inter-sectoral collaboration throughout the city, and encouraged optimism that the city

can secure an economic future around clean technologies. In 2008, the green energy cluster initiative was established, with the goal of building on the success of the biotech cluster to continue advancing economic re-vitalization while catalyzing a sustainable energy transition in the region. An intermediary organization, the Institute for Energy and Sustainability (IES), was established, with support from the state government and two local, private universities, to promote the cluster initiative, and a diverse set of actors and institutions have been working through both integrated and parallel efforts to develop the initiative.

While the sustainable energy cluster initiative is still in the early phases of development, the initiative has emerged as a central organizing logic that permeates regional discussions around energy policy, economic development, and the pursuit of sustainability in the region. Analyzing the initiative from a socio-technical transitions framework allows us to assess whether and how the cluster initiative might contribute to achieving a sustainable energy transition in the region and beyond. With an intermediary organization focused primarily on economic development, the initiative evinces a different set of priorities, and a different pathway toward transition, than many niche-based strategies for sustainability transition. However, many of the elements of successful economic clusters—namely, institutional thickness, inter-sectoral collaboration and trust, and the promotion of dynamic, learning regions—could advance socio-technical change in the region as well.

The case offers an opportunity to consider these regional planning issues within the socio-technical transitions framework. The goals of this research are to review the early phases of development of this sustainable energy cluster initiative in Central Massachusetts in order to understand the role that such green energy cluster initiatives play in advancing socio-technical transitions toward energy sustainability, and to consider the implications of the green cluster strategy for the socio-technical transitions framework. The research is based on information accumulated from over 20 in-depth interviews with key actors from different sectors and institutions, including the IES, universities, city government, community groups, and utility companies, in addition to the review of primary documents, including formal reports, minutes of meetings, and news articles. In addition, the authors have been actively engaged in the green energy cluster initiative through a participant observation role that includes monitoring and evaluating the intermediary organization, the IES, and contributing academic expertise in the context of multi-stakeholder planning meetings. The research has been designed so that the empirical details of the case can inform a more general understanding of the role of economic cluster initiatives in the transition process, contributing to the growing body of work that views socio-technical

transitions as regionally embedded, place-transforming processes.

The first section of the paper introduces the cluster strategy for regional economic development, and it describes the application of the cluster strategy to the sustainable energy sector. It then presents a brief background on the evolution of the socio-technical transitions literature in order to highlight the need for more integration of regional policy and planning considerations such as economic development initiatives. In the next section, we describe the empirical details of the sustainable energy cluster initiative in Worcester. After providing a brief background on the city of Worcester and its existing economic profile, we characterize the region's energy system by describing the three conceptual levels of the MLP—the broader energy landscape, the entrenched regime, and innovative niche technologies—as they are expressed in this particular region. The final section draws on this case study to discuss the potential of sustainable energy cluster initiatives to accelerate change in entrenched energy regimes, and it discusses ways in which insights from cluster theory may expand socio-technical transitions frameworks.

Background on sustainable energy clusters and socio-technical transitions

The cluster strategy for regional economic development

The promotion of economic clusters has become a central strategy for regional development. The approach builds on theories of industrial agglomeration, which describe how firms experience positive externalities, or agglomeration economies, associated with their geographic proximity to related firms—either horizontally linked firms engaging in cooperation or competition, or vertically linked suppliers and producers—and that the competitive advantages for clustering firms generate spillover effects for the regional economy (Bathelt et al. 2004; Deutz and Gibbs 2008). The factors of agglomeration, which were first described by Marshall in his work on small firm districts in England in the nineteenth century, include lowered transport and transaction costs, localized infrastructures of specialized services, pools of expertise and know-how, and distribution networks and supply structures (Marshall 1920). Clusters received heightened attention in the later twentieth century, as researchers and planners sought to understand how, in spite of the competitive pressures of an increasingly globalized economy, some localities retained and enhanced their regional economic dynamism through spatial clustering and specialization in key sectors. Important examples include technology intensive clusters such as Silicon

Valley (Saxenian 1994), Boston (Harrison and Kluver 1989), and the M4 Corridor in greater London, as well as specialized industrial districts producing quality consumer goods such as the movie industry in Los Angeles and the craft furniture industry in Northeast Central Italy (Storper 1997).

Building on these observations, regional planners and policy-makers have sought to proactively stimulate clusters as a strategy for promoting economic vitality, and the cluster strategy has emerged as a dominant objective in regional economic development policy worldwide (Porter 2000; Martin and Sunley 2003). As a policy strategy, cluster initiatives involve utilizing public support to attract firms in the desired sector, support employee training and job development, and cultivate networks and institutional innovations that link firms and non-firm actors such as research centers and universities. Most attention has focused on promoting clusters in technology-intensive sectors, which are seen to have high growth potential and to benefit particularly from spatial clustering among firms. Positive externalities associated with the co-location of firms in knowledge-based sectors are seen to lie in the transfer of tacit knowledge between firms and related institutions, which occurs through labor mobility (Saxenian 1994), observational and interactive learning (Vincente and Suire 2007), formal and informal interactions among actors in a region (Bathelt et al. 2004; Casper 2007), and shared cultural traditions and habits within a particular industrial cluster (Saxenian 1994; Amin 1999). Cluster initiatives seek to promote these interactions in order to create dynamic, learning regions capable of sustaining growth and innovation, and ongoing regional competitiveness, even as the global economy changes.

Cultural norms, regulations, and shared expectations of actors within a region are seen as institutional rules which shape regional characteristics, such as innovative capacity (Saxenian 1994). Recognition of the importance of the institutional environment in promoting economic clusters has led to a de-centering of the firm in favor of a multi-stakeholder focus that involves a plurality of interdependent organizations and networks associated with the particular economic sector (Amin 1999; Baxter et al. 2005; Arikian 2009). Government programs often provide early support for cluster initiatives, utilizing multiple mechanisms, including financial support for intermediary organizations, to facilitate cluster development. Other non-business organizations support agglomeration tendencies by providing expertise on government regulations and standards, product testing, market research, and financial services. Among non-state organizations, universities and research centers play a unique and central role in cluster generation (Cooke 2001; Bramwell and Wolfe 2008). These knowledge-based organizations are critical for

attracting and training knowledge-based workers, generating local research and development which result in knowledge spillovers to the broader community, and co-developing innovative technologies. Amin and Thrift (1995) describe how cluster initiatives are most successful when they cultivate an 'institutional thickness' supporting the sector in the region, and others have noted the importance of generating a 'buzz' of activity and information exchange around innovative sectors (Bathelt et al. 2004).

Application of the cluster strategy to the sustainable energy sector

Sustainable energy cluster initiatives aim to stimulate local and regional economic development by creating the conditions that attract and promote innovative firms in the area of sustainable, renewables-based energy (KanEnergi 2007; Porter et al. 2008). Firms engaged in the development and implementation of renewable energy technologies, smart grid technologies, and low-impact transportation systems are particularly sought, as these sectors are seen as high growth sectors with potential to both address critical sustainability challenges and solidify and advance a region's knowledge-based economy. It is expected that these firms will benefit from the same agglomeration economies that have long benefited firms in other clustering industries, and that these firm-based activities will generate economic spillovers that will promote dynamism in a local green economy. The 'green' cluster strategy is rapidly emerging as a regional development and sustainability planning approach worldwide. Examples are found in large 'green-field' development projects, such as Masdar City, United Arab Emirates, and several emerging Chinese eco-cities (Normile 2008), in mega-cities seeking to transform their economic base toward clean, high value-added economic activities, and in mature urban centers seeking to reinvigorate regional economies around sustainable economic activities (KanEnergi 2007; Porter et al. 2008).

Sustainable energy clusters differ in important ways from other industries conventionally supported by cluster initiatives. An important distinction is rooted in the breadth of the sustainable energy sector. Whereas life science firms, for example, were spurred by scientific discoveries with clear applications, the greentech sector is more diffuse and lacks defining technologies. It encompasses an amalgam of industries, including the electricity, transportation, and building industries; it involves both industrial- and individual-scale applications and decisions; and it includes both supply-side technology deployments and demand-side technologies that increase energy efficiency. In addition, innovation cycles in the sustainable energy sector may be slower than those in other industries, as firms can take years to develop products, such as solar panels, batteries, or

biofuels, which are capital-intensive and require long lead time ventures. The legacy of publicly supported regional monopolies in the energy sector has also resulted in a complex and diffuse regulatory environment in the energy sector, which discourages regional competition and works against the standard setting. Sustainable energy cluster initiatives also face greater challenges associated with the path dependence of the existing energy regime, a barrier that is not as great for other clustering industries. Finally, the market structure for sustainable energy products and services is very different from other clustering industries, as it relies on inducing demand.

In spite of these differences, the broad institutional support that has been critical in other knowledge-based cluster initiatives can underpin sustainable energy cluster initiatives. State institutions, including city and state governments, contribute by establishing renewable portfolio standards or greenhouse gas emissions targets, through purchasing requirements and state expenditures that support sustainable energy activities, and by supporting intermediary organizations and other associations involved in promoting green or sustainable activities. Universities have emerged as critical actors in sustainable energy clusters, providing intellectual and scientific background for sustainability transitions and collaborating in research and engineering activities (Stephens et al. 2008; Stephens and Graham 2010). The effort to create green energy economies is also supported by a range of non-governmental organizations, including those focused on job creation, materials recovery and recycling, and community development.

Locating green clusters in the evolving socio-technical transitions literature

Emerging out of the unique Dutch academic and planning context, the socio-technical transitions framework has been increasingly embraced worldwide as a central concept guiding climate change response and sustainability planning (Smith et al. 2010). Drawing on a robust body of case studies on transitions in large and complex technical systems, the approach is rooted in a systems perspective which emphasizes that transition processes involve innovation and technological change, along with coordinated changes in the range of social practices and institutions which support these technologies, including regulation and policy, cultural beliefs and values, behavioral expectations and practices, governance structures, learning traditions, and market structures (Loorbach and Rotmans 2006). Empirical case studies have detailed transition dynamics in a range of systems, including transport (Elzen and Wiczorek 2005; Geels 2005a, b), energy (Verborg and Geels 2007), water and waste systems (van der Brugge et al. 2005), housing (Brown and Vergragt 2008), and food (Smith 2006b).

Analytical interest has focused on deciphering the trajectories through which these systems undergo transformation. The predominant model explaining the socio-technical transition process is the MLP (Rip and Kemp 1998; Geels 2001; Smith et al. 2005), which describes transitions as the result of interactions among actors, institutions, and technologies at the three conceptual levels described above: the landscape, regime, and niche levels (Geels 2005a, b; Genus and Coles 2008). Following a decade of elaboration (Rip and Kemp 1998; Smith et al. 2005; Geels 2010), the MLP model offers a robust conceptual framework for analyzing the major dynamics at play in the transition process: the emergence of niche experimental activities, the path dependence of entrenched regimes, and the larger environmental and societal pressures from the landscape level. Much research in the socio-technical transitions literature has focused on elaborating and expanding on the basic MLP model to reveal the dynamic interplay of factors involved in the transition process (Smith et al. 2005; Smith 2006a; Brown and Vergragt 2008). Adaptations have also been proposed to highlight dynamics that are not well-accommodated in the MLP, such as the interaction of discourses, policy networks, and institutions (Jiusto and McCauley 2010).

A central critique of the MLP framework is that it describes the transformation of socio-technical systems without sufficient attention to the actual places and contexts in which transitions unfold and, therefore, that it remains an abstracted model of transition without providing guidance for sufficiently understanding or promoting transitions on the ground (Smith et al. 2010). Recent transition studies have made progress in addressing this gap. Hodson and Marvin (2010) have explored the role of cities in socio-technical transitions, while Vergragt and Brown (2010) have explored socio-technical transitions as community development efforts. Deutz and Gibbs (2008) integrate industrial ecology and regional development approaches to highlight overlap between eco-industrial development initiatives and cluster policy. Several other papers have introduced considerations of space and the benefits of geographic proximity into some work on socio-technical transitions (Truffer 2008; Coenen et al. 2010; Späth and Rohracher 2010). Building on this work, Truffer and Coenen (2012) map out the geography of sustainability transitions as a field of research. Still, given the ubiquity of green energy cluster initiatives and their obvious connections with sustainability planning and policy at the regional level, there is a need to explicitly consider the role of such clusters in socio-technical transitions.

Regional sustainability clusters can be conceptualized as conveners and coordinators of a collection of niche activities in a region, i.e., by supporting the development, demonstration, and implementation of new, experimental

technologies and social practices. In addition, by attracting firms and investment, cultivating a broad and supportive institutional environment, and coordinating resources for sustainable energy activities, cluster initiatives provide a mechanism to accelerate the movement of niche-level technologies and practices to the regime level. The same objectives pursued in conventional cluster initiatives to promote agglomeration economies among firms—fostering networks, promoting the expansion of existing firms, facilitating innovation, attracting new firms and talent to the region, and creating a brand for the region—can support a socio-technical transition if they contribute to the increasing pressures on the fossil fuel energy regime. Rather than promoting specific niche technologies, sustainable energy clusters are concerned with creating the regional conditions that support a range of potentially transformative niche-level technologies, firms, endeavors, and social practices that advance sustainability. The cluster strategy can build capacity and networks among niche activities, allowing such activities to coalesce into a broader, multi-faceted socio-technical transition, while also providing inroads to the established power elite and core regional decision-makers.

On the other hand, regional economic development initiatives conventionally emerge through, and rely on the support and participation of, established business and civic leaders who, in many cases, have been closely associated with the institutions and social practices which co-evolved with and maintain the entrenched regime. The path dependence of established networks, policy formations, and incentive structures can lead cluster strategies to favor technologies or practices which promote and sustain the status quo or at least favor small incremental changes over transformative changes and, in this sense, they can reinforce rather than destabilize the established regime. In the conceptual framework of the MLP, cluster initiatives thus occupy an intermediary space spanning the niche level and the established regime level, with potential to either accelerate or inhibit regime level change. They likely do both in a non-linear and iterative process. The case study below describes the evolving green energy cluster initiative in Central Massachusetts with the goal of deciphering how such an initiative contributes to a potential sustainable energy transition in the region.

The sustainable energy cluster initiative in Central Massachusetts

This section explores the empirical details of the emerging sustainable energy cluster initiative in Central Massachusetts. First, background on the region and its experience with a previous cluster initiative in the biotech sector will

be described. Then, a summary of the region's sustainable energy context is provided within the three-level framework of the MLP model. This context sets the stage for an in-depth description of the sustainable cluster initiative and its contribution to the transition process.

Background on the region

Central Massachusetts is generally considered to be the segment of Massachusetts west of the metro Boston area and east of the Amherst/Berkshire mountains. The largest city in the region is Worcester, a mid-sized city with a population close to 185,000, which lies approximately 45 miles (72 km) due west of Boston. Like other post-industrial cities, Worcester faces the challenge of generating new sources of economic vitality. The city grew and prospered in the years between the industrial revolution and World War II with an industrial focus on metalworking and machine tools, but faced economic decline through the second half of the twentieth century. The economic decline of the past several years has continued to weaken the regional economy and slowdown the housing market, negatively affecting property values and reducing city tax revenues. In spite of these challenges, a robust knowledge-based sector has been sustained in Worcester and Central Massachusetts over the last several decades, lead by the biomedical/life sciences, health services, and higher education sectors. The city has experienced growth within each of these sectors over the last several years (City of Worcester 2004; Worcester Municipal Research Bureau, Inc. 2008). The greater Worcester area is home to 13 colleges and universities that combine to serve 30,000 students and employ 11,000 people.

The sustainable energy cluster initiative in Central Massachusetts was motivated in a large part by the region's successful biotech cluster initiative which, since its inception in the early 1980s, has been a key driver of growth in the region's knowledge-based economy. The biotech cluster initiative grew out of the engagement of a group of civically minded business leaders and the strong support of city and state governments and local universities, and many attribute the success of the initiative to the collaborative disposition among actors and organizations in the region. As a second-tier city in the shadows of Boston, many in Worcester openly express a sense of necessity regarding collaboration and cooperation among different sectors. The biotech cluster has become an increasingly important anchor in the regional economy and a key component in the state's economic development initiatives. The Worcester area is a central node in the Massachusetts life sciences super-cluster, which is now one of the largest, best known, and most established centers for biotechnology research and development in the world (Cooke 2002).

The landscape-level context for sustainable energy in Central Massachusetts

Sustainable energy activities in Worcester reflect the broader landscape of energy transition, including climate and energy policy at the national and international levels. Currently, policy formation at both levels faces significant hurdles and uncertainties. At the international level, the Kyoto Protocol was recently extended for another 5 years, yet, it does not require emissions reductions from the world's leading emitters, and the agreed framework for establishing a new international climate agreement does not anticipate action until 2020. The US, the world's largest economy and one of the largest emitters of greenhouse gases, plays an important role in international climate negotiations, yet, the political system in the country has been an obstacle to the formation of national-level climate policy.

While the failure of the US to pass a national climate policy is inhibiting both global climate policy and the creation of incentives that would speed the deployment of non-fossil fuel energy options domestically, cities and states in the US are taking a lead role in advancing climate action via a bottom-up strategy. Massachusetts is a state with relatively high climate change awareness compared to other parts of the US, and the state is part of the nation's first regional cap-and-trade regime for power plants, the Regional Greenhouse Gas Initiative (RGGI). Massachusetts has also been ranked second to California among the leading clean energy states in terms of regulatory and financial incentives, knowledge capital, and economic and workforce development (Clean Edge, Inc. 2010).

The landscape for energy system transition in Central Massachusetts is also shaped significantly by the broad-based economic recession. Massachusetts was not as heavily affected by the recent financial crisis as some other states, and the region's sustainable energy sector has benefited from federal funds dispersed to Massachusetts through the national-level American Recovery and Reinvestment Act of 2009. This economic stimulus package included \$438 million from the Department of Energy to 120 companies in the sustainable energy sector in Massachusetts and \$32 million to fund 114 solar projects and produce 20.7 MW of solar installation in the state; overall, Worcester County was awarded \$19.1 million in the area of clean energy and the environment. However, private sector financing for major development projects remains relatively restricted.

The entrenched energy regime in Central Massachusetts

The entrenched socio-technical regime is understood as the relatively stable, reinforcing configuration of technologies

and infrastructures, as well as the institutions, rules, practices, and networks that define the system (Rip and Kemp 1998). The entrenched energy regime in Central Massachusetts reflects the region's development around fossil fuel energy sources for electricity, heating, and transportation, with a small but growing renewable energy sector.

Massachusetts is a net electricity importer, as in-state electricity production is less than the electricity demand and consumption. Massachusetts residential customers pay substantially more for electricity than the national average, and prices have risen substantially since 2004, due largely to the increased price of natural gas, which is the dominant fuel for electricity generation within the state. In 2009, the electricity generation mix in Massachusetts included 43.6 % from natural gas, 22.8 % from petroleum, 12.2 % from coal, 5 % from nuclear, 4.1 % from renewables, and 12.3 % from pumped storage. Massachusetts has a deregulated, competitive market for electric power. It does not have any known coal or oil deposits, and has one operating nuclear plant.

With regard to heating, Massachusetts relies on oil, with close to 50 % of its home heating provided by that source. The region experiences a cool climate with a long and severe heating season. The housing stock within the city of Worcester is characterized by older wooden structures, particularly the characteristic triple deckers built to accommodate factory workers in the early twentieth century. The transportation system in Central Massachusetts reflects the general structures of suburbanization and automobile dependency characteristic of urban areas throughout the US. Transportation accounts for 31 % of all energy consumption in Massachusetts and is almost entirely fossil fuel-based. The region has some public transportation, including a city bus system run by the Worcester Regional Transit Authority (WRTA), and a commuter rail line into Boston, but schedules and routes for public transportation are limited and most residents rely on automobiles for transport. Changes in the transportation sector face the daunting challenges of overcoming path dependency in interdependent infrastructural systems such as refueling stations, parking arrangements, and highway networks.

Niche-level sustainable energy activities in Central Massachusetts

A variety of niche-level activities associated with sustainable energy have emerged in the Central Massachusetts region over recent decades. Among these are the Central Massachusetts Safe Energy Project, which promoted alternative energy solutions in the late 1970s and early 1980s. At Clark University in Worcester in the early 1980s, a combined heat and power cogeneration system was

installed with a grant from the Department of Energy, representing a leading effort to demonstrate organizational energy efficiency (DeCarolis et al. 2000). More recently, the Holy Name Central Catholic Junior/Senior High School installed the first wind turbine in Worcester with technical assistance from college students from Worcester Polytechnic Institute (WPI), while the Community Development Corporation in Worcester installed solar panels on ten affordable housing units in the city of Worcester. These efforts, and numerous others like them, establish the foundation of niche sustainable energy activities in the region. These niche activities have been supported and encouraged by a range of organizations, including grassroots environmental NGOs, the universities, and the city and state governments. While niche-level activities continue to emerge, the need for enhanced communication and coordination to achieve the synergistic potential of these different initiatives is acknowledged by some key actors.

The Central Massachusetts sustainable energy cluster initiative

Given the multi-level sustainable energy transition context described above, this section provides a more in-depth empirical account of the development of the sustainable energy cluster initiative in Central Massachusetts. The goal of this section is to provide details which enable exploration of the dynamics of the emerging cluster and of the potential for the initiative to contribute to a broad-based sustainable energy transition.

The coordinated effort to foster the development of a sustainable energy cluster in the region began in 2008 when a Massachusetts politician, state representative to the US Congress Jim McGovern, approached the presidents of two of the city's private universities, Clark University and WPI, and asked them to provide an assessment of their organization's strengths related to sustainable energy and to identify potential opportunities for the development of a sustainable energy cluster in Central Massachusetts. A multi-sectoral steering committee was established to facilitate what was envisioned as a center for economic revival based on the emerging 'green economy' in Worcester and Central Massachusetts. An intermediary organization, the IES, was created and supported with funds from the Massachusetts Clean Energy Center and with logistical support from the two universities, and an executive director of this non-profit organization was hired in late 2009.

The mission of the IES has been described in different ways, but it generally includes benefiting Worcester and the surrounding area by: (1) creating green jobs, (2) increasing energy efficiency and reducing greenhouse gas emissions, (3) supporting the establishment of Worcester as

a national leader in sustainability, and (4) supporting research in the science of sustainability and sustainable technologies. Key strategies to accomplish these objectives include branding the region as a nationally competitive Green Business Zone and attracting, growing, and retaining green businesses through zoning, permitting, and tax breaks. In addition, supporting research at the universities, including hydrogen fuel cell research at WPI and socio-technical transitions research at Clark University, and supporting and coordinating workforce development, training, and outreach to increase energy efficiency within the community have been articulated as key strategies (IES 2010, 2011). In addition to business outreach and promotion efforts, the IES's recent activities have included partnering with area universities to install electric vehicle re-charging stations. While its mandate to coordinate and stimulate cluster activities is broad, the IES has embraced a largely business-centered approach to cluster development.

In 2009, the clean energy sector overtook textiles as the tenth largest industry in the state, and there is some shared perception among the business community that Central Massachusetts already hosts a burgeoning cluster of clean-energy companies. One leader of a small renewables-based power company described the region as "a hotbed of what's happening in clean energy." Firms identify the supportive role of city and state government, as well as the region's strong manufacturing tradition, which has shifted toward more complex, technical manufacturing, as strengths for the sector. A preliminary survey of clean energy firms in the region conducted by the IES identified 63 firms in Worcester County being connected in some way to clean-energy activities. Of the major utility companies, National Grid has been particularly engaged in sustainable cluster developments, providing financial support for the IES and developing an ambitious smart grid pilot project which awaits state approval.

Recent developments suggest that private sector actors are beginning to coalesce as a 'greentech' community. A corporate conference organized by the IES in March 2010 attracted over 100 community leaders, many from the business community. A smart grid investor showcase, also organized by the IES in 2011, attracted over 100 participants, including startup green energy companies and investors. The enthusiasm generated from that showcase, along with several investment partnerships spawned by the event, has led to planning for a followup showcase in 2012. After a relative absence from sustainable energy discussions for the first several years of the cluster initiative, the Worcester Chamber of Commerce in 2011 embarked on an effort to promote economic activity in the sector.

While the IES, as an intermediary organization tasked with stimulating the cluster initiative, is an identifiable center point, the initiative comprises a broad collection of

other horizontally related organizations. The City of Worcester has been making major advances toward sustainable energy as part of the implementation of the city's climate action plan. A new staff position, the Energy and Conservation Manager, has been coordinating several sustainable energy developments, including major energy efficiency upgrades to over 80 municipal and school buildings in the city, creating a rebate program for energy efficiency improvements in homes, and creatively engaging in community outreach efforts to raise awareness about energy-saving programs and opportunities. In May 2010, Worcester was designated as one of the state's Green Communities, a prestigious designation achieved by satisfying specific criteria, including ease of siting for renewable energy projects, expedited permitting for eligible energy companies, a 20 % municipal energy reduction plan, a high fuel efficiency vehicle fleet purchase policy, and the adoption of an enhanced energy-efficient building code. Upon receiving the designation, the city released a statement informing that the Green Communities designation will "enable the City to market itself on a regional, national and global basis as a city that is attractive to companies in the sustainable energy sector, thus boosting our economic development, business attraction and expansion activities" (City of Worcester 2010).

The region's universities have played a key role in the cluster initiative since its inception. In addition to providing leadership and logistical support to the establishment of the IES, the region's universities are involved in multiple niche-level sustainable energy initiatives, including developing climate action plans, building energy-efficient LEED-certified buildings, supporting faculty and student research in both technical and social aspects of sustainable energy, and providing renewable energy training programs at local community colleges. Importantly, the universities have facilitated integration among other sectors, particularly by organizing innovative planning forums to bring together actors from very different sectors within the region. One such forum, the Worcester Housing, Energy, and Community (WHEC), was created in 2009 by faculty researchers at Clark University as a place to bring together community groups, business leaders, local government officials, and researchers to explore a large-scale strategy to enhance energy sustainability in the city's residential housing (Vergragt and Brown 2010).

Worcester's sustainable energy cluster initiative also draws on a strong network of grassroots and community-based organizations engaged in city-wide sustainability efforts, including the Regional Environmental Council (REC), the Worcester Energy Barnraisers, and the Worcester Green Jobs Coalition, which recently created the Empower Energy Co-op, a grassroots initiative in which ex-prisoners in the Worcester area cooperatively produce

waste vegetable oil biodiesel fuel. The Worcester Community Action Council, Inc., the city's federally mandated anti-poverty organization, is actively engaged in energy efficiency upgrades and in advancing sustainability networks in the city. These initiatives are among dozens of others in the city and region which are advancing the broad agenda to create an inclusive and just sustainability movement in the city.

Since its relatively recent inception, the IES has focused on integrating a broad spectrum of constituents, and it has faced some challenges with respect to connecting with all of the relevant niche-level activities in the region. A clear focus on business-to-business services has emerged within the IES, while other organizations and actors have been concentrating on other aspects of sustainable energy development, including enhancing the efficiency of the housing stock, achieving energy self-sufficiency for community members, and implementing and deploying more efficient and renewable technologies and practices.

During these first 3 years of the IES's development of the cluster initiative, a challenge has been to effectively ensure a sense of participation and engagement from a diverse set of stakeholders. Some stakeholders have not felt sufficiently involved or engaged in the cluster initiative and have perceived an institutional emphasis on connecting with corporate leaders and potential new business opportunities to the neglect of community outreach, engagement, and implementation activities. Several interested researchers from universities in the city expressed a desire for more information and communication about cluster activities. Meanwhile, although the multiple grassroots and community organizations working toward a more sustainable energy economy in the region may share the broad objectives of the IES and its business partners, their intentions and strategies differ considerably. Among some stakeholders interviewed, there were expressions of distrust of the business-centered approach embraced by the IES.

The sustainable energy cluster initiative in Worcester thus demonstrates considerable complexity at this early stage. There are clear signs of commitment and enthusiasm among many sectors in the city, and the numerous networks and forums that have emerged in the last 2 years already point to the emergence of an institutional thickness that is critical for successful cluster initiatives. At the same time, there are tensions within this multi-sectoral effort, and questions remain about the potential for the cluster initiative to promote a transformation of the region's energy system.

Discussion

The empirical analysis of the early development of the Worcester regional sustainable energy cluster initiative

provides important insights on the role and potential of clusters to facilitate sustainability transitions.

Potential for clusters to facilitate transition

This case suggests various ways in which the cluster initiative has begun to build a movement toward social and technical change around sustainable energy. The state-supported cluster strategy has resulted in increased coordination between the city's universities, city government, and the IES, which has generated a sense of strong institutional buy-in throughout the city. While many sustainable energy activities have been initiated by actors and groups not formally affiliated with the cluster initiative in any explicit way, making it difficult to ascribe causality to the cluster initiative, there is widespread awareness through the region of this growing institutional commitment to energy system change. Numerous multi-stakeholder forums have been established and are growing in size and representation, with banks, the Chamber of Commerce, and other private sector interests recently joining what had previously been largely public and non-profit-sector representatives. In spite of perceived differences between these actors, a common vision is emerging: a vision that includes substantial energy upgrades in residential and commercial buildings, creative financing for renewable energy projects, coordination between energy system change and community development, and large-scale public-private projects with transformative potential. Although it is in the early stages of development, the initiative appears to be cultivating the institutional thickness that has been identified as a key factor in the promotion of dynamic, learning regions. As more actors and organizations are drawn into renewable energy activities and sustainability planning forums, there is a growing regional 'buzz' around sustainability initiatives and energy transition in particular. This buzz contributes to the economic, social, and cultural changes that are necessary for achieving a broad transition in the region's energy system.

Potential for clusters to impede transition

While analysts of sustainability transitions continue to debate relationships between radical and incremental change (Loorbach and Rotmans 2006), the transitions literature acknowledges that moving toward sustainability requires radical transformation in important human systems, such as transportation, housing, and electricity provision. The economic cluster approach, as a strategy for sustainability transition, thus raises a paradox. On one hand, the approach draws in powerful actors and organizations who can advance renewable energy initiatives at the regional level, mobilizing niche technologies and

practices as part of mainstream development activities in the region. On the other hand, the business development orientation, and the focus of the cluster first and foremost as an economic growth strategy, has the potential to impede radical change and provide resistance to changes in the status quo. By supporting actors who demonstrate high potential for growth in the current system, the cluster strategy could make the innovation environment more difficult for some fringe, alternative actors who may be working toward radically different ideas or technologies that may be deemed impractical by cluster facilitators. Some tension in this area was identified in the case study, as different priorities and assumptions of moving toward incremental versus radical change was evident between the central cluster actors, particularly the IES, and more peripheral participants representing grassroots community-based groups that might be characterized as having more radical assumptions of change. Some actors from grassroots and community groups, as well as university researchers, perceived the business focus as creating barriers to participation in decision-making related to cluster activities.

Trust between firms and with supporting non-firm actors is widely acknowledged as a key factor in the success of economic cluster initiatives (Dupuy and Torre 2006; Yamamura 2009). Whether it reflects fundamental incompatibilities between their visions of sustainability or simply different perspectives on decision-making processes, issues of trust could directly or indirectly limit support for innovative, emerging niche technologies and social practices. The unique characteristics of the green energy sector (e.g., its combination of high-tech and low-tech products and services, the need to stimulate consumer demand, the embeddedness of energy systems in the everyday practices of consumers) suggest that a green energy cluster initiative must engage community members to a much higher degree than cluster initiatives in other sectors. The criteria of trust in a green energy cluster, therefore, extends beyond interested firms and their direct supporters to encapsulate this broader set of stakeholders.

Green energy broadens the conventional notion of clusters

While supporting the innovative practices of firms remains a central focus in sustainable energy cluster initiatives, our research points to the importance of cultivating a broad-based, multi-sectoral sustainable energy movement in the region. Scholarship on cluster initiatives has increasingly emphasized the importance of non-firm activities and institutional thickness, but economic cluster initiatives remain guided by the logic of generating innovative firms that can underpin the region's competitiveness in global

markets. The case of green energy clusters de-centers the notions of market competitiveness and firm expansion. These pursuits remain important parts of the cluster initiative, but questions of community development and cultural change related to energy practices also figure centrally into a successful green energy cluster.

Non-firm actors are taking a stronger leadership role in this cluster initiative than that seen in cluster initiatives in other sectors. Universities have exhibited a particularly strong role in stimulating the cluster initiative. They have spearheaded the cluster initiative, provided space for multi-sectoral forums, and they are increasingly emerging as possible leaders in real estate development projects associated with cluster activities. In the context of the broad-based economic recession, they also provide a stable institutional and economic presence that can support local and regional economic activity. As non-profit, public-interest organizations, they also have a stronger mandate to address non-economic aspects of cluster development, including social justice concerns and socio-technical transitions. Grassroots groups and community organizations, including anti-poverty organizations, also play a key leadership role in the green cluster initiative. These groups have direct access to segments of the population that benefit the most from first-order energy system changes, such as residential energy upgrades. Progress toward a sustainable energy transition, and, indeed, the vitality of a green energy economy, relies on the integration of these non-business sectors.

Expanding socio-technical transitions frameworks: lessons from cluster theory

The cluster strategy for economic development draws on a well-established set of economic geographic principles, and applications of the strategy in hundreds of regional development initiatives around the world has revealed lessons for promoting successful economic clusters. These lessons can provide important insights for promoting socio-technical transitions for sustainability. Where socio-technical transitions have been largely concerned with the evolution of technologies, cluster theories describe the economic and institutional interactions that create the conditions for regional dynamism and change. Knowledge-based theories of clustering, in particular, emphasize the importance of promoting tacit knowledge exchange between actors in a region. Creating institutional thickness and overlap is seen as being centrally important. Analysts of cluster initiatives have also noted the importance of 'buzz,' the source of collective learning that occurs as actors are surrounded by a milieu of rumors, impressions, recommendations, and strategic information (Grabher 2002; Bathelt et al. 2004). Given the importance of cultural

and behavioral change for a sustainable energy transition, generating local buzz may be particularly important in this sector. Perhaps most importantly, economic cluster initiatives have emphasized trust-building, and our study confirms the importance of trust between multiple, diverse stakeholders in regional sustainability initiatives. In general, cluster theory sees innovative capacity as a regional attribute that can be developed and promoted through policy. Applied socio-technical transition approaches may similarly learn to promote the transition capacity of regions.

Conclusion

Given the growing prevalence of green energy clusters worldwide, it is important to consider their merits not only for promoting some form of 'green economy,' but also for accomplishing the urgent task of stimulating a transition toward more sustainable energy systems. This research explores green energy clusters from a socio-technical transitions perspective. Our review of one sustainable energy cluster initiative shows how the cluster strategy can play an intermediary role connecting niche-level activities with regime-level institutions, and possibly facilitating the diffusion of niche technologies and practices at the regional level. In the case of the Central Massachusetts sustainable energy cluster initiative, the level of commitment to a sustainability transition appears high, as multiple and diverse stakeholders are engaging in new and innovative forums to cooperate on sustainable energy endeavors. On the other hand, there are creative tensions within the process, and it is not clear whether the initiative is reaching its potential. The case suggests that whether a cluster initiative ultimately promotes socio-technical transition, i.e., whether a cluster fosters the diffusion of niche-level activities throughout the region, depends on factors that have as much to do with institutional interactions and governance arrangements as with technological and economic concerns.

Policy strategies to encourage a sustainable energy transition have focused primarily on technological innovation, including research and development (R&D), demonstration, and deployment of specific sustainable technologies (Gallagher et al. 2006). In the US, for example, much of the public support for renewable energy has been in the form of financial benefits for specific renewable technology projects (Milford et al. 2012). While this focus on technology is critical, these public investments tend to pay only minimal attention to the social and cultural elements of transitioning energy systems. Applying the cluster strategy to the sustainable energy sector invites a perhaps more holistic approach to facilitating

sustainable energy transition. The cluster strategy, if framed in appropriately broad and inclusive terms, has the potential to facilitate social learning and social change in addition to technical innovation and change.

We recognize that these considerations are early in their development, and there is a need for continued critical analysis of green energy cluster initiatives, as well as continued exploration of the role of economic development initiatives in promoting socio-technical transitions toward sustainability. We have sought in this paper to stake out some of the important considerations related to these topics. Given the minimal attention within much of the socio-technical transition literature to regional economic development considerations, this work adds an important element to socio-technical transitions frameworks and the multi-level perspective (MLP). By articulating the role of regional cluster initiatives, the work also demonstrates the embeddedness of socio-technical transition processes in space and place, thus, grounding the otherwise somewhat abstract MLP model.

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