Title: Energy transition management as a 'spatial strategy'? Geographical implications of the transition toward renewable energy

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Abstract:

This paper considers the geographical implications of the transition toward renewable energy (RE). We argue that the unique physical properties or 'materialities' (i.e., quality, quantity, location) of emerging energy resources are at the root of disruptive change to physical and social landscapes, and therefore of social resistance to policy efforts aimed at a sustainable energy future. This argument is substantiated empirically using mixed-method research in the Canadian province of Ontario, and supported by an extensive review of literature. Commensurate adaptive / innovative institutional design principles and policy recommendations, which might help to minimize the unintended impacts and seize the opportunities that emerge throughout the transition process, are identified.

1. Introduction

The social and environmental imperatives to replace non-renewable with renewable energy (RE) resources are strong, and the technological means by which to achieve this goal are available and improving. The problem, however, is that a systemic and self-referential preference for fossil energy resources has been deeply entrenched within social and political-economic activities as well as their underlying institutional and physical structures over the last three centuries (see Unruh, 2000; Nye, 2001; Huber, 2013); an era described by Shaffer (2009) as 'hydro-carbon man'. A full transition toward RE requires coordinated social action formalized in legislative and institutional adjustments which disrupt the momentum underpinning fossil energy systems in order to accelerate the development of new energy resources and the deployment of emerging energy technologies (see van den Bergh & Bruinsma, 2008; Eberlein & Doern, 2009; Weiss & Bonvillian, 2009; Loorbach & Rotman, 2010 for examples). This represents a new era in the energy-society relationship; one of 'energy transition management'.

While an energy transition can be measured through time as a gradual shift from one mix of resources and technologies to another, its geographical implications are more profound. In fact, "major shifts in the ... energy mix have often underpinned broad social and geographical change" (Bridge et al., 2013: 531; see also Hoare, 1979; Spooner, 2000; Juisto, 2009; Pasqualetti, 2013). While these changes are socially mediated rather than natural forces (see Nye, 2001), they are driven primarily by differences in the spatial distribution and physical properties between emerging and incumbent energy resources; i.e., "cultural and political-economic factors co-evolve with changes to the quality, location, and environmental impact of energy resources" (Juisto, 2009: 533). Perhaps most importantly, although the decision to shift from one fuel mix to another might be socially accepted in principle (e.g., due to new social values surrounding the energy-environment interface as is currently the case), the willingness to endure these more fundamental disruptions to the prevailing spatial legacy lags behind (Pasqualetti, 2011a & 2011b).[1] In other words, the success of RE transition management is not based solely on high rates of initial RE technology uptake and industry development. Equally important is the capacity of transition managers to identify and communicate the limitations and negative impacts associated with the intensive development of RE resources and to adapt governance structures and practices accordingly.

Profound questions emerge from this perspective in the context of active and emerging government support for RE development and implementation: (1) in what ways are RE resources materially different from incumbent energy resources; (2) how are prevailing energy landscapes disrupted by, and responding to, these differences; and (3) how can energy governance structures and practices be adapted in order to manage subsequent challenges and opportunities? Currently, however, the geographical qualities of RE remain underexplored (Solomon et al., 2004; Bridge et al., 2013) and the literature surrounding the theory and practice of energy transition management is silent on how they influence the development and implementation of transition management schemes (Smith et al., 2010). The persistence of these gaps in our understanding is at least partly attributed to the fact that these questions are difficult to answer prior to actual experience with substantial rates of RE implementation (Brown & Sovacool, 2007).

The purpose of this paper is to address the questions raised above through an analysis of RE development and implementation within the Canadian province of Ontario. At the turn of the century Ontario's transport sector was serviced almost entirely by petroleum-based liquid fuels, and in 2003 provincial electricity supply was generated predominantly by the usual suspects - uranium, coal, oil and natural gas. Over the last decade, transformation in the fuel mix of both sectors has been driven by changes in public policy. Notable among them are the Ontario *Ethanol in Gasoline*

[1] This disconnection between social values and willingness to accept the burden of the physical manifestations of those values is part of what Bell et al. (2005) refer to as the 'social gap' problem (see also Hall et al., 2013).

Regulation (2007) (EGR); the federal *Renewable Fuels Regulation* (RFR) (2011); and the *Green Energy and Green Economy Act (2009).* Presently, ethanol and bio-diesel consumption represent no less than five per cent and two per cent of gasoline and petroleum-based diesel, respectively, in the province. Over 1100 Ml of ethanol production capacity and 300 Ml of biodiesel production capacity is installed or under construction as a result of the EGR and RFR (CRFA, 2011). Various efforts to encourage the use of lignocellulosic material (i.e., non-food feedstocks) for biofuel production are underway (Mabee, 2013), and the province has also considered doubling the ethanol and biodiesel blending mandates. The GEGEA is primarily focused on renewable electricity generation. Its fiscal incentive involves the most comprehensive feed-in tariff (FIT) program in North America, which has followed and greatly outpaced previous bidding and standard offer programs (see Yatchew & Baziliauskas, 2011; Stokes, 2013). As of the latest round of public announcements, contracts for over 4,600 MW of installed capacity have been executed under the FIT program (Amin, 2012; Stokes, 2013). In total, more than 2,500 MW of renewable electricity has achieved commercial operation in the province, with more than 7,000 additional MW under contract. As of 2012 emerging RE systems generated four per cent of Ontario's total electricity production and as of 2011 wind and solar began generating more electricity than coal-fired systems (Amin, 2012). The province is on-track to increase non-hydro RE production capacity to 10,700 MW by 2018 (OPA, 2012a).

In order to answer the stated research questions an exploratory mixed-method research approach is taken. The geographical qualities of RE resources and their influences over RE implementation are examined through a review of literature; descriptive spatial and statistical analyses of RE projects within Ontario; and content analysis of policy and planning documents surrounding RE development within Ontario. Policy and planning challenges associated with these geographical properties are identified through triangulation of the aforementioned material with information gathering through personal attendance and informal discussions at public meetings held by the

Ontario's electricity system planning authority as well as a content analysis of public posts and appeals on Ontario's Environmental Registry regarding RE projects.[2] Through iterative coding, five key properties of RE are identified as having the greatest impacts on prevailing energy landscapes and therefore on energy transition management. Each of these is discussed in turn in the following section. Section three considers these properties from the perspective of energy governance and energy transition management. The paper concludes with a discussion of future research imperatives.

2. The geographical implications of renewable energy implementation

2.1 Immobile and localized.

Fossil and fissile energy resources are distributed on a global scale through highly interconnected transportation systems. As a result, primary energy resources providing power to light-switches and thermostats in Ontario might be sourced from a coal seam in Pennsylvania, a uranium ore in Saskatchewan, or an oil and gas pool in the Middle East. In addition, conversion facilities can be located where most convenient. In stark contrast the use of RE resources re-introduces the friction of distance into energy systems (Calvert & Simandan, 2010). Natural flows of RE (including solar insolation; air-mass transfers; hydrological discharge; falling water; wave and tidal movements; and geothermal temperature gradients) cannot be transported and must therefore be converted into useable forms of energy at the site where they occur. Biomass can be transported so that energy conversion is not limited to the immediate site of resource occurrence, but the relatively low energy density by weight and volume of unprocessed biomass makes bioenergy supply chains highly sensitive to the energetic and economic costs of transportation so that bioenergy systems are

[2] The Environmental Registry is an online consultation ('e-consultation') platform where proposals for infrastructure projects that will have environmental impacts in Ontario are made available for public viewing, comment, and appeal before project approval (see Winfield, 2013: 73-74).

localized (Hamelinck et al., 2005). A number of profound changes stem from the immobile and localized nature of RE resources.[3]

2.1.2. Shrinking scales of production

RE resources cannot be centralized with the same scale and intensity as fossil and fissile energy resources. The scale or rate at which RE facilities can deliver useable forms of energy is therefore naturally limited; a limitation that is magnified where competing land-uses prevent energy sprawl and therefore scale-up (we elaborate on this point in Section 2.3).[4] In Ontario, for instance, the average installed capacity of a renewable electricity facility in Ontario is approximately 20 MW while the largest project (on-shore wind farm) is rated at approximately 300 MW. In contrast, over 6,000 MW of power can be delivered using by the Bruce Generating Station in Ontario using uranium, and the *average* installed capacity of the province's natural gas fleet is approximately 300 MW. Ontario's largest biofuel production facility (corn-ethanol) has a nameplate capacity of 400 Ml which represents a daily throughput of 40-50,000 gigajoules (GJ). Techno-economic models of advanced biorefineries show that a *large scale* facility might process up to 6,000 oven dry tonnes (ODT) of material per day (see Kocoloski et al., 2011) which represents approximately 104,400 gigajoules (GJ) (assuming an

[3] Conversion of immobile energy flows into a mobile energy carrier can overcome the friction of distance associated with RE flows. The obvious example here is hydrogen (Dunn, 2002). The development of a hydrogen economy is significantly delayed, however, given that few of the conversion pathways in the hydrogen domain are anywhere near to economical and there are still significant technical uncertainties surrounding hydrogen storage and distribution (Romm, 2007). Furthermore, raw biomass can undergo an energy densification process – e.g., pelletization or gasification – to be distributed globally. Due to relatively low energy density, the net energy returns of long distance transport of bioenergy products degrades rapidly with distance and, depending on total distance and final conversion efficiency, could be negative (see Moriarty and Honnery; 2011; Magelli et al., 2009). Furthermore, it is important to keep in mind that while long-distance flows of electricity are possible, the substantial increase in transmission infrastructure is subject to considerable siting difficulty (Vajjhala and Fishbeck, 2007) and in almost all cases distant resources are more expensive to exploit than local resources which can be incorporated into existing distribution infrastructure (Hoppock and Patiño-Echeverri, 2010).

[4] The largest solar electricity facilities in the world are in Californian deserts: the Topaz facility is a 550 MW ground-mount solar PV farm (Davis & Jordan, 2013) and the Ivanpah facility is a 392 MW concentrating solar power plant (Levitan, 2013). The largest on-shore wind farm is the Alta Wind Energy Center in Kern County, California (1,370 MW) while the largest off-shore wind farm, at 870 MW once fully completed, is the London Array (SmartMeters, 2012). The largest operational biopower plants are in Europe, which draw much of their feedstock from Canada and the U.S.: the 742 MW plant in Tilbury and the 810 MW plant in Copenhagen are notable. Only large-scale hydropower currently challenges incumbent energy systems on scale: the Three Gorges Hydroelectric Dam in China at 22,500 MW is more than twice the size of an average oil refinery on a GJ basis. Proposed tidal power systems are also large, with schemes on the Severn ranging from 4-10,000 MW (Hoare, 1979).

average higher heating value of 17.4 GJ/ODT). In stark contrast the *average* oil refinery in Ontario is five times larger at approximately 85,000 barrels or 518,500 GJ of daily throughput (assuming an average higher heating value of 6.1 GJ/barrel).

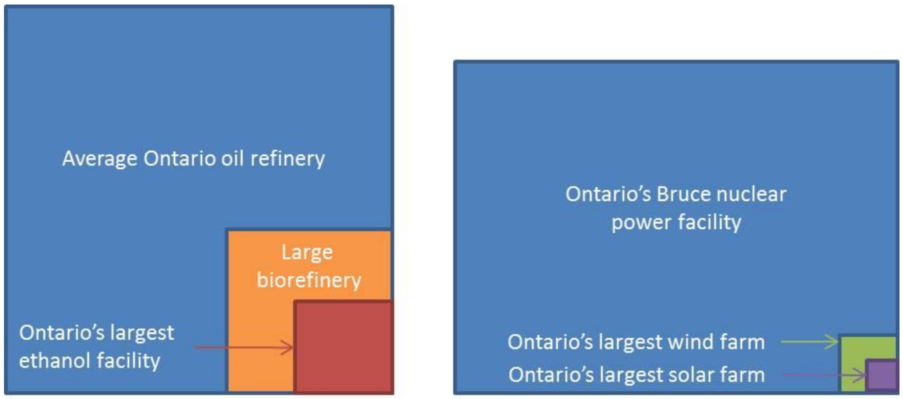

Figure 1: Graphical depiction of relative nameplate capacity on a GJ basis for fuel (left) and electricity production (right) using renewable and non-renewable resources.

2.1.3. Unfamiliar local landscapes and new (local) political economies

One of the corollaries to shrinking production scales is that the number of individual conversion units required to service the energy demands of a given area necessarily increases. Because RE production facilities cannot be centralized in relatively few locations and dislocated 'out of sight, out of mind' as has historically been the case for fossil and fissile energy systems, the integration of RE resources into the fuel mix exposes an increasing number of communities and individuals to energy production and conversion activities. In other words, the boundaries between spaces of energy production and spaces of energy consumption are dissolved through RE development and implementation. This trend is apparent in Figure 2, which maps 'host' communities for energy production facilities in Ontario before and after the coordination and execution of RE implementation programs.

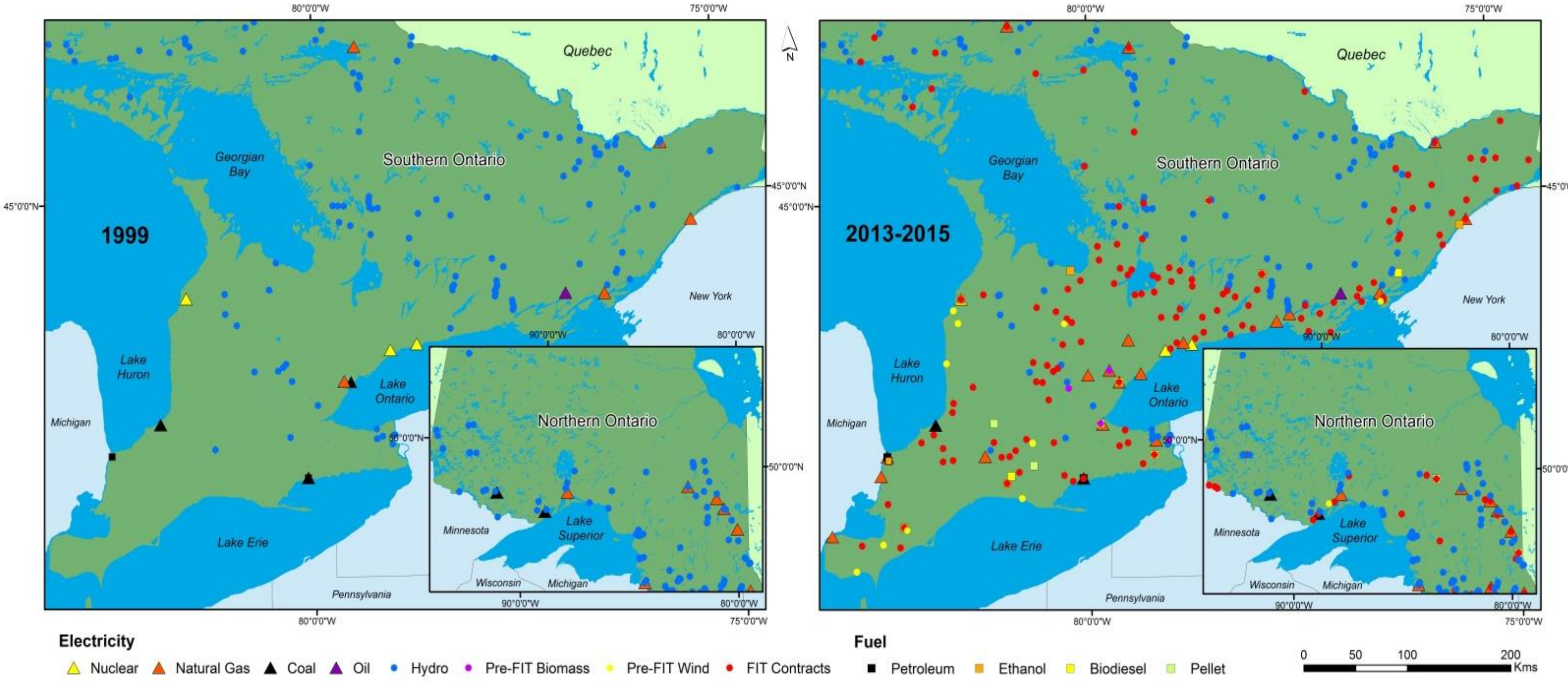

Figure 2: The changing geography of energy and fuel production in Ontario. Facilities are located by city name. Note that in the FIT category a single city hosts as many as 1-7 individual projects, not including small scale (<10kW) projects. The biomass category includes landfill gas and digester gas. All coal fired power plants are planned for decommissioning or conversion to gas / wood pellets by 2014-2015.

Since many of the communities now hosting RE projects were previously unfamiliar with energy production activities and its associated infrastructure, the implementation of RE production tends to violate preferred landscape aesthetics and land-uses / land values (see also Ellis et al., 2009; Miner, 2009; Selman, 2010; Pasqualetti, 2011a & 2011b). Indeed, RE systems are often perceived as foreign 'space invaders' rather than as acceptable additions to the local landscape. This sentiment is exemplified in claims that communities in Ontario have become "infested" with wind turbines (see Smith, 2012). Landscape issues are a focal point for opposition in other jurisdictions as well, including in Germany where "some are angry at the way the landscape, celebrated by German Romantic poets such as Hölderlin and Mörike, is being butchered" (Schulz, 2013).[5] These sentiments are tied to the fact that support for RE drives a new land-based economy, so that the provision of existing local landscape functions is often disrupted or displaced entirely in favour of RE production.

[5] On the upside to all of this, there is some evidence to suggest that these unwanted and contested additions to the landscape may be the most effective motivator to reduce personal energy consumption and to maximize energy efficiency (see McEvoy et al., 2000; Luna, 2008).

This might involve cultural services, as when pastoral landscapes are fused with the industrial flavour of wind turbines or when heritage landscapes are mixed with high-tech landscapes (e.g., the recent solar development on Dunster Castle in the United Kingdom; see Vaughan, 2008); ecosystem services, as when native grassland is converted to grow and cultivate dedicated bioenergy crops; or non-energy land-based services, as when edible landscapes are converted to energy landscapes in order to establish regional corn-ethanol supply chains.

These unfamiliar, frequent and profound interactions with energy infrastructure have changed the way in which the general public is implicated in policy and business decisions in the energy sector (see also Furlong, 2011). In response to landscape issues and concerns over the ways in which the costs and benefits of RE are distributed, a noticeable (re)localization of spatial energy politics has emerged even as Ontario's government has re-scaled or re-appropriated siting rights from municipal to provincial agencies to prevent disjointed local policies and disempower local opponents as a way to foster a more 'investor friendly' environment (see Stokes, 2013). Partly as a way to mediate the tension between groups who perceive RE as an 'assault' and those who perceive the trend as an opportunity to revive ailing local economies, but also to prepare for the new pressure on land and resources caused by RE systems, 'community energy plans' are emerging in Ontario (St. Denis & Parker, 2009; McIntyre et al., 2011; Tozer, 2013). In other 'first mover' jurisdiction such as Germany, the UK, and Denmark local governments are also increasingly leading the transformation toward a renewable future through mandates and local support of RE projects (Bale et al., 2012; Yapp, 2012; Klagge and Brocke, 2012). New localized social networks are also forming outside of official governance spheres. The number of registered community energy co-ops in Ontario has grown from zero to almost 80 in under a decade; a trend aided in part by rule changes within the GEGEA which loosened the red tape surrounding co-op formation. Recently, there has been an on-going initiative by the Trillium Energy Alliance (TEA) to organize and integrate community energy co-ops across the province (TEA, 2012). This push is motivated in part by the increasing organization of social groups on the other side of the debate, exemplified by 'Ontario Wind Resistance' which is a provincial organization composed of over 50 local wind opposition groups from across the province. Aboriginal groups across the province are also viewing RE development as a 'new path forward' in their quest for economic self-sufficiency as well as environmental stewardship within their communities (Krupa, 2012).[6] In all cases, linkages between sometimes disparate and otherwise disjointed social groups (e.g., cottage associations; bird watchers; nature conservancy groups; aboriginal peoples) are created through shared interests in ensuring that corporate growth strategies in the RE sector engage local citizens their values, and to be sure that RE projects "earn their place" (Parkinson, 2013) where the use of local landscapes and natural resources is concerned.

But it is important to recognize that while local economic activity is a potential benefit of RE implementation, the shift toward distributed and localized RE systems will not by itself counterbalance entirely the dynamics of economic globalization and international economic integration that characterize energy markets. This fact is exemplified by the World Trade Organization's ruling against Ontario's attempt to bootstrap provincial RE project development to a provincial energy technology manufacturing sector through a content requirement on parts and labour (ITCSD, 2012; Stokes, 2013). Moreover, while RE resource and distribution systems are necessarily localized their supportive social networks, including the capital, knowledge, and technologies that are necessary to realize the transition to RE, are not (see Vinodrai et al., 2012). In Ontario, for instance, local shareholders who initiated RE projects and secured contracts through various programs often partner with international developers with experience and competencies that

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[6] This stands in stark contrast to the suspicious and confrontational manner in which these communities have traditionally viewed and approached extractive energy industries.

can see the project through to completion.[7] In fact, only 3.5 per cent of applications submitted to the FIT program by June 2013 were 'community owned' despite price adders that paid a premium for projects developed under such ownership models (OPA, 2012b); difficulty encouraging community ownership is not unique to the Ontario experience (see Gipe, 2012).

Localizing the indirect economic benefits of RE production is therefore a matter of carefully crafting energy policy within the constraints of international trade rules and the dynamics of international economic integration more generally. Recent adjustments to Ontario's FIT program have focused on aggressive and deliberate regulatory rule changes to encourage community ownership through higher premiums and project prioritization schemes, and require evidence of majority local support before a project is approved. The evolution of Ontario's support for ethanol is also exemplary here. Initially, ethanol production, distribution and consumption was supported through an excise tax exemption on ethanol. This tactic ultimately stimulated investment into the economies of those nations where ethanol could be produced and supplied at the lowest cost (e.g., Brazil). With the introduction of the EGR in 2007, the tax has been reinstated and subsequent revenue allocated toward the subsidization of a domestic production industry through capital grants and operational support. Since raw material to support the industry must be sourced locally, the year in

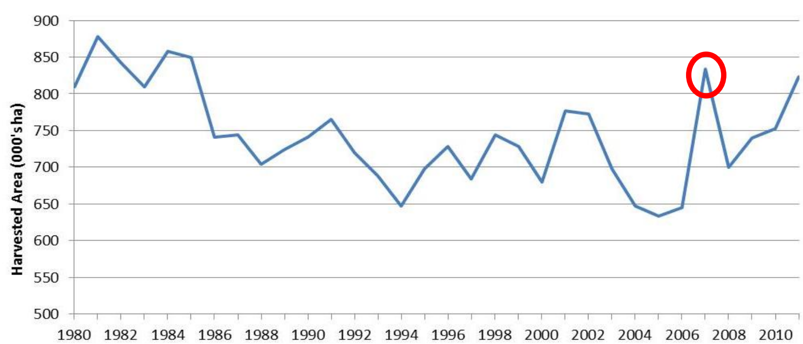

Figure 3: Timeline of harvested area under corn in Ontario. In 2007 (marked by the red circle), Ontario's EGR was enforced and land area under corn increased 188,000 ha, the highest absolute and second highest relative increase on record. Source of data: Grain Producers of Ontario (2012).

[7] As Yergin (2011) points out, the scale economies of the Danish wind turbine manufacturing industry were driven by American developers stimulated by Californian tax credits. It also helps to remember that merger and acquisition activity following reduced government support for RE in many first-mover jurisdictions has seen most domestic manufacturers of RE system components being purchased by Chinese interests and in many cases production is being outsourced to China (Ernst and Young, 2012; Goodrich et al., 2013). In fact, seven of the top 10 solar PV manufacturers are located in China, with Yingli Green Energy of China claiming the top spot (Lian, 2013).

which the EGR was implemented corresponded to the year in which Ontario recorded its highest absolute and second highest relative year-to-year increase of land area planted under corn; a welcomed reversal of previous trends for grain producers in the province (see Figure 3). Over 1100 Ml of ethanol production capacity continues to provide a market for more than 2 Mt of corn in the province and supports considerable employment along the supply chain (Mabee, 2013). But as the preceding paragraph showed, and as discourse analysis of these policies has revealed (Calvert, 2009), these allegedly 'home grown' policies are driven by external as well as internal dynamics.

2.2 Geographically sensitive (context dependent)

The implementation of RE means that private and public investment planning in the energy sector is no longer a matter of finding a single project that can deliver energy services to a significant portion of the consumer base. The number of siting decisions for energy generation units that need to be made at various levels of society is therefore greatly increased. Compounding the increased frequency with which siting decisions need to be made is the fact that RE systems are more strongly sensitive to their physical, social, and regulatory settings than incumbent energy systems (Calvert and Simandan, 2010). This geographic sensitivity is expressed in three ways.

First, RE production is *site-specific,* meaning that the scale, intensity and timing of energy production are absolutely limited by the physical constraints and primary productivity of a given area – including aspects related to climate, land-cover, and terrain (Mellino et al., in press). Where a given site has been deemed suitable to host a RE system the physical terrain and natural intensity of RE flows strongly impacts project design including technology selection, facility size, and micro-siting (e.g., the layout of individual energy recovery units) (Searcy and Flynn, 2009; Leijon et al., 2010; Skoglund et al., 2010; Beck et al., 2013). RE fuel mix targets and project-level system designs must therefore reflect the specific constraints and comparative advantages offered at a particular area or site, in stark contrast to fossil-fuel or nuclear thermal electricity production facilities which can be 'cookie-cutter' designs and draw resources of a specific quality from a large geographic area.

RE development is also *site selective*, even for those resources that can be found anywhere on Earth's surface (e.g., wind and sunlight). The development of RE as well as associated infrastructure can be excluded from an area if one or a combination of the following conditions are not met: (a) within a reasonable distance of demand and / or (b) within a reasonable distance of distribution infrastructure that has the capacity to transport energy products; (c) politically accepted as designated for such purposes; and (d) not currently supporting some other (higher) valued activity. These selection criteria are 'place-based' in that they are rooted in initial socio-economic and technical conditions, especially those related to purchasing power, infrastructure and local cultural value systems (see Zahran et al., 2008; Ferguson-Martin and Hill, 2011; Rygg, 2012; Slattery et al., 2012; Ek et al., 2013). And while these factors also influence fossil energy systems, coal and gas can be transported to more convenient areas for final conversion while RE resources cannot.

Location is also a critical factor in determining the cost-benefit ratio of a given RE investment. Solar, wind and geothermal energy technologies, for instance, have long been competitive against fossil fuel systems on a levelized cost basis for electric loads in remote or isolated locations so that these areas are preferred from an investment standpoint especially as RE technologies have improved and petroleum prices have risen (Thompson and Duggirala, 2009). Through financial assistance programs including tax exemptions and feed-in tariffs, however, the RE market is expanding geographically (with some limitations, as discussed above). 'Remoteness' is therefore no longer the sole factor that drives an attractive cost-benefit ratio for RE development. In addition, *non-monetary* benefits of a prospective investment are strongly sensitive to siting decisions. While this has a clear regional component (see Siler-Evans et al., 2013), there are also opportunities at a localized or site-specific level including: siting decentralized RE systems to alleviate congestion in the electricity system (Lewis, 2010; Brandstätt et al., 2011); subsidizing wood pellet use in a low-income rural area relying on heavy oil to maximize greenhouse gas emissions abatement (Samson et al, 2008) as well as social welfare (Kaygusuz, 2011); growing dedicated bioenergy crops on or near contaminated sites to decrease leaching of specific heavy metals and / or to recycle saline waste water (Mirck et al., 2005); and siting off-shore wind turbines to create artificial reefs and / or to delineate commercial fishing exclusion zones (Punt et al., 2009; Nienhuis and Dunlop, 2011).

It is important to note that, unlike site-specific factors, site-selection criteria can be deliberately modified over reasonable time periods through, e.g., changes to infrastructural conditions, social attitudes, and regulatory reform. These changes either expand or contract the capacity of an area to absorb RE production activities and alter the spatial pattern of sites that are permissible or attractive for RE implementation. There is also a feedback between technological innovation and site-selectivity to consider, as new technologies or system designs often change which sites are suitable or acceptable for implementation. Möller (2010), for instance, demonstrates how existing land-use restrictions for wind energy development based on visibility and ecological impacts can become obsolete as hub heights and rotor diameters increase. The dynamic nature of technology and its relation to site-suitability is especially significant in areas where sites that have been deemed suitable for development are saturated and must be repowered with larger and more efficient systems in order to increase productive capacity (e.g., replacing a 1MW wind turbine with a 5MW turbine) (see Ohl and Eichhorn, 2010; Ernst and Young, 2012).

2.3 High local land requirements.

While non-renewable energy recovery involves digging for mineral deposits, RE recovery involves surface-mining reproductive surpluses of net primary productivity. The surface area available to support RE production activities, described as an area's 'carrying capacity' (Carrion et al., 2008), is therefore the primary constraint on RE potential and development. Site-specific and site-selective constraints can reduce overall carrying capacities by 40-50 per cent (Dominguez et al., 2007). This raises significant questions about land requirements of, and land availability for, RE developments; questions which boil down to the crucial distinction between energy and power as it relates to mobile and immobile energy resources (see also Smil, 2010 & 2011).

The land use requirements of an energy resource can be measured in terms of energy density (e.g., giga-joules (GJ) or megawatt-hours (MWhr) per square meter) or power density (e.g, megawatts (MW) installed per square meter). The former is a measure of the *amount* of work that can be performed using the resources derived from one square meter of land. The primary source of RE–i.e., nuclear fusion reactions in the sun–will drive RE flows (e.g., solar; wind) and the growth of RE stocks (e.g., biomass) for billions of years at a rate that is more commensurate with human consumption, so that higher land occupation times of a RE conversion system yield higher levels of energy recovered per unit area. In fact, one square meter of land collects more solar energy than is contained in a barrel of oil after only a single year, and will continue to provide energy over the lifetime of the system without ever running out of energy inputs (Lovins, 2011). Conversely, the energy contained in fossil fuels per unit area is available once every epoch.

Power density, in contrast, is a measure of the *rate* at which work can be performed per unit area. This measure is arguably a more suitable basis for comparison of energy systems, because the rate at which energy can be delivered is more important to social value systems than total energy production (Peet, 1992; Bryce, 2010). Greater flow rates in mineral resource recovery (e.g., larger boreholes and pipelines) and larger energy conversion facilities can greatly increase power potential per unit area with minimal horizontal (surface area) sprawl required. Natural flows of RE, on the other hand, are mostly available at Earth's surface and travel at fixed rates so that the ability or RE systems to deliver increasing rates of energy scales directly with surface area. Furthermore, while there is considerable energy potential in renewable resources, crucial uncertainties remain about the *rate* at which said energy can be extracted at a given site without compromising the integrity of local ecosystem functions (see Kludze et al., 2010; Schmidt et al., 2012; Howard et al., 2013).

What this all suggests is that while the limits of fossil energy are related to quantity, the RE limit is one of rate (Cook, 1976: 118). Moreover, the only way to overcome this limitation is to expand the overall land footprint of our energy system so that our ability to achieve relevant rates of energy production through RE systems relative to fossil energy systems is land intensive at local scales (see Table 1). When an importing jurisdiction decides to allocate a certain percentage of a fuel mix toward fossil or fissile energy systems, land requirements can be mostly discounted as a domestic policy concern since activities related to resource recovery, as well as their direct environmental impacts, are mostly located outside of jurisdictional boundaries. When allocating the same percentage toward RE resources, however, the implications on local land base must be seriously considered since all aspects related to RE are centralized at or near the site of resource occurrence (see also Howard et al., 2009).

Table 1: Comparison of land use intensity by electricity facility in Ontario.

Facility	Installed Capacity (MW)	Plant Footprint (ha)[a]	Local Land intensity (ha/MW)
Bruce GS (uranium)	6,300	929	0.15
Atikokan GS (coal)	211	300	1.42
Kingston North Solar[b]	100	261	2.61
Enbridge Solar	80	456	5.56
Enbridge Wind Farm	181	5,600	30.94
Melancthon Wind Farm	199.5	15,000[c]	75.19
Atikokan GS (biomass)	211	79,428[d]	376.44

Source of data: company websites, unless stated otherwise.
[a]Includes unit spacing; excludes indirect impacts such as visibility, distribution infrastructure, or health impacts
[b]Based on project planning report; facility not yet constructed
[c]From personal communication, Melancthon Wind Farm Operator
[d]Assuming 20 year facility operation at 8 per cent capacity, and an annual pellet throughput of 90,000 tonnes (see Arnott, 2010) or approximately 139,000 gt of wood. The average yield of forest harvest residues and unutilized wood in the region is 35 gt/ha, with an average rotation period of approximately 60 years (see Alam et al., 2012a and 2012b).

Bioenergy and biofuels deserve particular attention where land use is concerned, since they are by far the most land intensive (Fthenakis and Kim, 2009; McDonald et al., 2009). Ontario's five per cent blending requirement mandated by the EGR, for instance, requires on average over 2.14 Mt of grain corn annually which represents anywhere from 20-30% of the annual corn harvest by tonnage.[8] Assuming an average corn yield of approximately 9.5 t/ha, approximately 212,000 ha of agricultural land is required which represents 20-25% of the annual corn planting (grain and silage) or 4-5% of the total area of farmland in the province (source of data: OMAFRA, 2012). This rate of land uptake relative to fuel consumption is clearly unsustainable, and policymakers readily admit that there was a woeful lack of attention paid to the implications of 'scaling up' bioethanol production in the province (Calvert, 2009).

Fortunately, there are a number of technological advancements that could reduce the land-use requirements of RE production. For solar PV systems, this includes maximizing the efficiency of single junction PV panels or developing multi-junction PV cells that absorb a wider range of electro-magnetic wavelengths (Şen, 2004; Luque et al., 2005). Solar PV/thermal systems, which convert solar irradiation that is not absorbed in the PV process into useful heat, are also being developed (Ibrahim et al., 2011).[9] Power output from individual wind turbines is increased by extending rotor diameter and hub-height, although this means that unit spacing must also increase in order to minimize interference between the individual units (Möller, 2010; Djikman and Benders, 2010). Land-use efficiencies of bio-energy production can also be drastically improved via the increased use of cellulosic biomass as opposed to, or in addition to, primary grain such as corn as well as advancements to biomass productivity (e.g., through genetic modification or efficient cultivar selection) or to conversion efficiency (e.g., higher hydrolysis rates; combined heat and power systems) (Lynd et al., 2009). As I discuss in the following section, there are also synergies within and between energy and non-energy land uses that could be explored in the near-term.

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[8] This assumes an optimistic average ethanol yield of 410 litres per tonne of corn.

[9] Irradiation is the sum of direct and diffuse solar energy that reaches a unit area per unit time (e.g., kWh/m^2/yr).

2.3.1 Spatially coincident.

Multiple sources of RE exist at any site that has been deemed suitable for energy generation. Biberacher et al. (2008) note that production potentials at a given location are not always additive and therefore land base is in some cases available for only one RE project. In addition to competition with existing land-based economic and social activities, RE systems will increasingly compete with each other for limited land resources especially as implementation intensifies and carrying capacities are strained within an area. Allocating this land toward one activity necessarily reduces the potential production capacity of the other. Since each particular resource and technology has its own costs and benefits related to energy provision (e.g., form; timing; ancillary benefits), there are a number of land-use trade-offs that must be considered in the competition for territorial advantage between various RE technologies.

Where feasible, however, multiple RE systems might be combined on the same land-base and in some cases two source-options can be incorporated into a single production system; what is referred to as 'hybridization' or 'synergy' (see Goetzberger and Zastrow, 1982; Nema et al., 2009; Leone, 2011; Shafiullah et al., 2012). Given the spacing requirements of wind turbines, for example, dedicated bioenergy crops could be grown between the series of generating units. Solar panels might be installed directly on wind turbine structures in which case panels would be spaced vertically rather than horizontally. In fact, Hoicka and Rowlands (2011) find that co-locating and co-operating wind and solar at a single location can 'smooth' electricity generation and help to mitigate concerns related to grid congestion, especially where resources are spatially coincident but available at different times throughout the day / season. These and other co-located and hybrid systems have obvious benefits to the extent that they (a) mitigate intermittency associated with solar and wind energy without resorting to utility scale battery or mechanical storage; and (b) maximize energy production per unit area and thereby reduce the footprint of RE infrastructure.

It is also important to note that land used for RE production in some cases remains viable for non-energy uses. This presents opportunities to ration and economize the RE carrying capacity of a specific area through multi-purpose land use schemes that involve RE production. Included in this category would be biomass residue collection since the land base retains its primary societal function – i.e., food or fibre supply. Other options include mounting PV systems on static infrastructure exposed to the sun for long periods of the day such as rooftops (Wiginton et al., 2010) or highway sound barriers (de Schepper et al., 2012); or growing shade tolerant food crops within a solar PV farm (Dupraz et al., 2011). Thin-film and screen printed organic solar cell technologies are especially worthy to note here, and recent efforts have incorporated them into window construction (Singh, 2012). With these advanced technologies in mind, researchers at the National Renewable Energy Laboratory (NREL, 2004) concluded that, in theory and landscape impacts notwithstanding, the US would not have to appropriate a single acre of new land to produce its electricity needs if existing infrastructure were used. A key issue to consider here is to balance supply with demand while ensuring constant access to the sun over the lifetime of these projects.

2.4 Fugitive (transboundary).

Solar, wind, and water energy are 'intermittent', which means that the availability and intensity of their energy flows fluctuate at daily and seasonal time scales. In the context of stable and predictable energy inputs from fossil and fissile resources, power systems and energy markets have evolved to expect a continuous flow of energy at a known rate. As such, considerable social and technical manipulations must occur in order to accommodate the temporal inconsistencies associated with many RE resources. When natural energy flows are being converted at rates that exceed demand, useful energy must be exported or dumped. From a balance-of-trade perspective net exports of a commodity such as electricity are usually favourable. In the case of RE, however, production is often subsidized above its international market value which results in a net-loss to the taxpayer. This is currently the case in Ontario; opponents of RE development stress the fact that wind electricity is paid $0.13/kWh per the FIT rate but receives only $0.025-$0.045/kWh when sold out of province (source of data: NEB, 2012).

One of the ways to manage the intermittent or interruptible nature of RE resources is to ensure a geographically diffuse pattern of development.[10] Given that the wind blows and the sun shines at different times at different locations, geographically dispersed and interconnected systems will increase the capacity credit of these resources since it is likely that at least a portion of them will be operating at any given time (Archer & Jacobson, 2007; Grothe & Schneiders, 2011; Hart & Jacobson, 2011). Recent technological developments are focusing on conversion devices and system designs that can operate at sites of marginal resources (e.g., low wind or poor sun angles) in order to achieve higher capacity factors and to smooth out supply. Intermittent RE systems can also be co-located with controllable RE systems such as biogas or hydro systems so that renewable rather than non-renewable resources are used for back-up generation. This geographic relationship is best described as 'production complementarity' or 'economic symbiosis' (Li et al., 2011). Indeed, when RE resources are managed collectively rather than individually, issues associated with market integration, system optimization, and net environmental benefits can be resolved.

In addition to being interruptible and therefore requiring careful and sophisticated integration into power systems, many RE systems are either *fugitive* (e.g., wind) or transboundary (e.g., solar; water) and therefore require careful integration into legal systems surrounding resource management. A resource is described as fugitive when it travels unpredictably through space and therefore does not lend itself well to stationary uses or to the fixed delineations of space upon which conventional political-economic systems and socioeconomic institutions (e.g., sovereignty and private property) are based (Giordano, 2003; see Figure 4). Trans-boundary resources also cross jurisdictional lines

[10] Alternatively, a co-located hydrogen production facility could be developed. This idea is not taken up in this paper.

and are not fixed in place, but their travel is relatively predictable in both time and space. In either case, these qualities stand in stark contrast to fossil and fissile energy resources which are spatially fixed (although they certainly have their own 'conflicted geographies' related to resource distribution, as witnessed in political disputes over pipelines and oil/gas subterranean migration; see Huber, 2013).

The fugitive and trans-boundary nature of RE resources presents two challenges to the organization and management of RE development (see also Elder, 1984; van der Horst & Vermeylen, 2010). Firstly, it places absolute limitations on our ability to decentralize energy systems within complex built environments. Although building-integrated wind and solar systems are desirable compared to industrial or utility-scale systems for a variety of reasons, surrounding obstructions can inhibit the flow of energy and therefore jeopardize the economic viability of an existing system operating 'downstream' of the resource. This is particularly problematic for proposed new RE systems within areas where obstructions have yet to take shape – for instance within large urban areas where condominium developers are racing to the skyline and planners are striving for greater density, or in young suburban areas where trees planted along the boulevard have yet to mature. Nguyen and Pearce (2012) have shown that such obstructions eliminate 50% of otherwise suitable rooftops from hosting micro-scale solar projects, although actual impacts are specific to the morphology of a given city. In other words, considerable changes to the morphological character of cityscapes, as well as personal attachments to them, would need to occur in order to implement a fully distributed energy system.

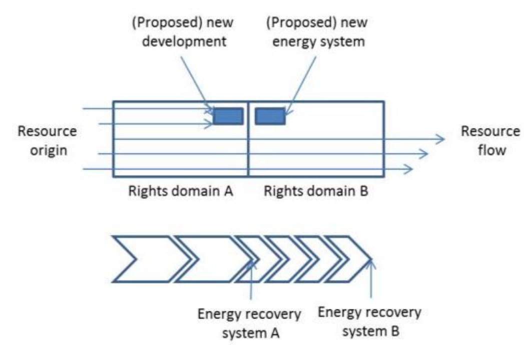

Figure 4: Complications with the trans-boundary nature of RE resources. Top: Property rights exercised in one domain (A) intercepting the energy flow available within another domain (B). Adapted from Giordano (2003). Bottom: Energy recovery systems developed upstream (A) reducing the consistency and intensity of resource flows at a downstream location (B).

In fact, Byrd et al. (2013) argue that low-density suburbs are more efficient in terms of their ability to capture and use solar resources - an argument that flies in the face of many of the geographical imaginaries related to 'transition towns' as well as ideas related to concentrate urban living through 'smart growth' strategies.

The fugitive nature of many RE resources also compounds existing concerns related to resource access. A RE project operating 'upstream' of the resource origin will greatly reduce and perhaps eliminate the energy production potential of an energy system operating 'downstream' (e.g., disturbed wind profiles; reduced river discharge). While impacts are relatively easy to quantify where water resources are concerned, because the directional flow is unidirectional, those for solar and wind energy are more difficult given that resource origins and directional flows are subject to the vagaries of daily and seasonal weather as well as the topographical / morphological structures within specific areas. These issues are especially apparent in the case where a land-owner wishes to install a wind turbine on a property that resides amidst an existing wind farm (van der Horst & Vermeylen, 2010). Here we have a situation akin to the 'rule of capture' whereby multiple private property owners have access to a single energy resource. While this political-economy of energy resources is familiar to early petroleum development in the U.S. (see Huber, 2013), this situations stands in stark contrast to the state ownership that characterizes most of the rest of the world's energy resources. Furthermore, while continuous resource access for fossil fuels or uranium depends largely on contracts with one or a few suppliers who have land-leases or ownership over mineral rights, resource access for 'flows' of RE, especially fugitive and intermittent ones, requires coordinated land-energy rules that address the complications illustrated in Figure 4 (Pursley and Wiseman, 2010) potentially hundreds or thousands) individual contracts with land owners.

3. What does this mean for transition management?

Competing models of the geographic development and implementation of RE systems exist: e.g., from those based on distributed generation to centralized models such as the proposed DESERTEC project. Technical challenges, concerns over energy security, and the role of energy production and consumption within regional economic development favour the former model, or at least a mix of centralized and decentralized production. In other words, the transition toward RE is also a shift toward the localization of energy production activities. As the research above has shown, this represents a drastic re-configuration of local infrastructure, land-use, land-based economies, and – perhaps more importantly – reconceptualization of local landscapes and people-place interactions. These changes do not necessarily signify a 'deglobalisation' of the energy sector, however, as there are clear signs of external geographic changes and new social, political, economic networks (e.g., international financing and expertise; trade in system components). Indeed, the Ontario example shows clear signs of competing territorialisations of the energy system as political and economic actors work to (re)scale the locus of power from local (through community energy plans) to global (by invoking the imperative to act on global climate change).

New geographies of energy challenge prevailing governance regimes that have co-evolved to manage and monitor fossil energy development and its prevailing spatial legacy and is therefore maladapted to the geographies of RE. In other words, grappling with the challenges and seizing the opportunities that emerge as RE systems are implemented means rethinking existing energy governance structures and practices. Currently, however, those tasked with energy transition management tend to focus on elements of policy enactment such as problem definition; reviewing alternatives; clarifying national policy needs / objectives; building coalitions; and creating 'spaces for innovation', with comparatively little attention paid to the challenges of actual implementation (Wolsink, 2007; Shove & Walker, 2007; Stokes, 2013; see also Hessing et al., 2005). This leads to hasty implementation of technology solutions which is among the primary reasons for failure and greater-than-necessary unintended consequences in all policy domains, but especially energy (Grossman, 2013). These flaws were apparent in Ontario, especially in the first iteration of their policy mechanisms; localities were stripped of the means to manage the ways in which new RE developments impacted their communities in material and immaterial ways; development was not prioritized; and the implications of scaling-up production not considered.

Underpinning these structural flaws of energy transition management is a narrow conceptualization of the energy, space and society relationship and therefore an under-appreciation of the core issues identified in this paper. Energy transition management in theory and practice currently conceives of geographical settings in terms of 'selection factors' for technology solutions (e.g., van den Bergh & Kemp, 2008; Coenen et al., 2012) and therefore focuses primarily on technical complications in the shift from centralized to decentralized distribution system designs, or on designing 'territorially sensitive' policy and technology solutions. Experiences with RE implementation in Ontario and elsewhere, however, show that rather than being exogenous selection factors, social, technical, and physical geographical settings are actually folded into or intricately entwined with prevailing energy systems. Governance structures must by modernized accordingly.

What should this new geo-governance of energy look like? Partial answers to this question can be found in literature. Policy recommendations include: decentralize the geographical scale at which transition management is strategized, implemented and monitored in order to achieve better 'institutional fit' between RE governance and the scale at which RE systems operate (Sarafidis et al., 1999; Wiseman, 2011; see also Cash and Moser, 2000); formulate local rather than national or provincial resource development and technology implementation roadmaps (Calvert et al., 2013); bring a land-based perspective to energy strategies by integrating energy planning and land-use planning (e.g., zoning based on local energy needs; structuring regulations or incentives to encourage specific locational choices) (Stoeglehner et al., 2011; Wächter, 2012; Blaschke et al., 2013); ensure that such land-energy planning (a) is in advancement of, rather than reactionary to, substantive RE development and (b) includes local voices and value systems at the strategic as well as the tactical level through stakeholder engagement (Nadaï & Labussière, 2009; Cowell, 2010; Howard et al., 2013) which might be achieved through participatory GIS methods (Calvert et al., 2013); update property rights / zoning to consider energy resource development, particularly the fugitive and transboundary nature of resource flows (Pursley and Wiseman, 2010); and use RE development as a focal point for new spatial identities and geo-political relations (Späth and Rohracher, 2010).

There are a number of challenges to consider when implementing these spatial strategies. Firstly, the underlying theme of localism and public participation not only clashes with prevailing geo-governance apparatuses which are largely executive-driven and operate at much larger (national and international) scales, but also with concurrent spatial strategies impacting energy provision and use; most notably the privatization of energy infrastructure which has shifted centers of power toward "private organizations with public duties" such as energy infrastructure planning, and which tend to pre-empt local authority in order to expedite RE development in favour of national and global interests (Groves et al., 2013: 353). Secondly, and as with technology solutions, there are no 'one-size-fits-all' participatory and planning processes that will resolve the scientific uncertainties and political tensions that challenge RE implementation (Anderson, 2013). The 'localization' or 'regionalization' of governing institutions will not in and of itself resolve implementation challenges. Thirdly, as power and responsibilities are (potentially) redistributed through the governance reforms recommended above, inconsistencies in activities between governance apparatuses operating at various political levels might magnify regulatory risk in energy investment planning (Nadaï, 2007; Ohl and Eichhorn, 2010) or disconnect planners from stakeholders (Cowell and Owens, 2006). Finally, the notion that governance structures and practices can be adapted to manage the changing geographies of energy is an inherently political project in terms of process and outcome. As such, these reforms can be (perceived to be) wielded as political resources to sustain or shift balances of power to serve particular agendas (Allmendinger and Haughton, 2010) and will inevitably (re)construct real and perceived social and environmental justice issues (Cowell, 2010). In other words, while perceptions of fairness and procedural justice leads to greater sense of legitimacy and therefore acceptance (Gross, 2007), the shared perception of procedural or distributive fairness and efficacy among all stakeholders implicated in these changing geographies of energy production and management is simply not possible. These intractable problems suggest that the spatial strategies which underpin energy transition management cannot be standardized but will rather require creative place-based solutions (see also Nadaï and Labussière, 2013).

4. Conclusion

The geographies of energy production and distribution are changing in fundamental ways with the emergence of sustainable energy technologies. Most notably, while the costs of fossil fuels are displaced over time (climate change) and space (exploitation of resources dislocated from major population centers such as the Alberta oil sands), the costs of RE are more immediate and localized. Identifying appropriate technologies and development strategies within the constraints and comparative advantages of particular geographical settings (i.e., being 'territorially sensitive' in terms of policy approaches) while adjusting distribution systems to be able to accommodate new developments (i.e., moving from hub-and-spoke to 'distributed' distribution networks) are necessary but by themselves woefully insufficient as a means of addressing the geographical challenges related to RE implementation. Transition managers also need to occupy themselves with the ways in which land-use plans, scales of governance, emotional attachments to particular places / landscapes, spatial identities, and socio-geographical networks are all entangled in their decisions as well. As jurisdictions increase their efforts to usher in a sustainable energy future, it will be critical to crossfertilize concepts and techniques in spatial planning with those from energy planning in order to develop underlying institutional design principles that are effective and consistent. What's more, these policy and planning adjustments need to be informed by a deeper understanding of how the ties between energy, space, environment and society are implicated in the intensive development of new energy resources.

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