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Geographies of energy transition: Space, place and the low-carbon economy

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HIGHLIGHTS

► Examines transition as a geographical process, reconfiguring patterns and scales of activity.
► Provides concepts for assessing geographical implications of transition to a low-carbon economy.
► Outlines location, landscape, territoriality, uneven development, scaling, and embeddedness.

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ABSTRACT

This paper makes a case for examining energy transition as a geographical process, involving the reconfiguration of current patterns and scales of economic and social activity. The paper draws on a seminar series on the 'Geographies of Energy Transition: security, climate, governance' hosted by the authors between 2009 and 2011, which initiated a dialogue between energy studies and the discipline of human geography. Focussing on the UK Government's policy for a low carbon transition, the paper provides a conceptual language with which to describe and assess the geographical implications of a transition towards low carbon energy. Six concepts are introduced and explained: location, landscape, territoriality, spatial differentiation, scaling, and spatial embeddedness. Examples illustrate how the geographies of a future low-carbon economy are not yet determined and that a range of divergent – and contending – potential geographical futures are in play. More attention to the spaces and places that transition to a low-carbon economy will produce can help better understand what living in a low-carbon economy will be like. It also provides a way to help evaluate the choices and pathways available.

1. Introduction

The ways in which societies secure energy and transform it to do useful work exert a powerful influence on their economic prosperity, geographical structure and international relations. Major shifts in the role of different fuels and energy conversion technologies in the global energy mix have often underpinned broad social and geographical change, such as those accompanying the transition from wood and water power to coal in the 19th century, or from coal to oil in the twentieth (Jiusto, 2009, Smil, 2010). The energy challenge in the twenty-first century is to bring about a new transition, towards a more sustainable energy system characterised by universal access to energy services, and security and reliability of supply from efficient, low-carbon sources.

Ensuring the availability and accessibility of energy services in a carbon-constrained world will require developing new ways – and new geographies – of producing, living, and working with energy. However, the geographical implications of this 'new energy paradigm' are not well defined, and a range of quite different geographical futures are currently possible. For example, low-carbon electricity generation can be achieved by large, remote actors (nuclear, offshore wind or large-scale solar) and long-distance transmission, via local mini-grids, or through highly decentralized micro-generation. Similarly, the different elements of a policy to promote energy security – from domestic investment in demand reduction to controlling and protecting overseas supplies – rest on assumptions about the geographical scale at which energy systems should be governed.

This paper has two general aims: (1) to illustrate how the low-carbon energy transition is fundamentally a *geographical process* that involves reconfiguring current spatial patterns of economic and social activity; and (2) to provide a set of basic concepts with which to map the geographies of a low-carbon energy system and

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so guide choices among different potential energy futures. These two aims are explored in the paper by reference to the geographical context of the UK. We adopt the UK as an illustrative case because low-carbon transition has been an objective of national government policy for nearly a decade (culminating in the adoption of the world's first long-term, legally-binding targets for carbon under the 2008 Climate Change Act); because many of the companies, markets and infrastructures that comprise the 'national' energy system of the UK are integrated into international economies in important ways; and because there is now widespread recognition – not only within the interdisciplinary field of energy studies but also within the UK policy community – that climate change, energy security, and the depletion of conventional oil reserves are re-working established patterns and scales of energy supply, distribution, and consumption (Anderson et al., 2008; Haas et al., 2008; Stern, 2008). The UK's Foresight Programme on Sustainable Energy Management and the Built Environment, for example, examined how the transition to 'secure, sustainable', low-carbon energy systems could be managed in part by re-examining the form, structure and spatial organisation of urban landscapes (Beddington, 2008). Research on the implementation of low-carbon electricity options highlights the different geographies and governance challenges associated with an energy future based upon large, remote facilities (like those for nuclear or offshore wind power) or highly distributed forms of household micro-generation (Watson, 2004). And at the global scale, numerous studies demonstrate how 'global energy challenges' are constituted through their particular, and often distinctive, geographies: the 2008 World Energy Outlook, for example, traces a looming world 'oil crunch' to the rapid growth of demand outside OECD countries, depletion in traditional basins serving OECD markets, and a new regionalisation in oil and gas markets (International Energy Agency, 2008).

Notwithstanding this acknowledgement within energy studies of some of the geographical dimensions of the new energy paradigm, the way in which spatial processes shape energy systems and influence their capacity for transformation has not been a focal point for analyses. Indeed, it is the temporal concept of 'transition' – rather than a geographical alternative – that is most often mobilised for thinking about the changes involved in developing low-carbon energy systems. As we examine below, 'transition' readily captures change over time for a given geographical unit (e.g., a country or a region) but frequently overlooks changes in the spatial organisation of the energy system and economic activity more widely. These geographical shifts are both internal (within a particular region or country) and *external* in that they involve relationships between one country/region and others. The UK Government's Low Carbon Transition Plan (LCTP), for example, is clear in its proposals for transforming the power, transport, housing, business and farming sectors of the economy by 2020, but does not reflect on the implications of these changes for the geographies of energy and economic activity within the UK (or, indeed, their implications for energy infrastructure and economic activity at regional or continental scales).

More recently, energy policy in the UK has begun to acknowledge the spatial dimensions of energy transition. The Coalition Government's Renewables Road Map (2011), for example, includes regional, map-based assessments of low-carbon deployment potential which identify some of the geographical options for increasing the contribution of renewable energy technologies to 15% of UK energy consumption by 2020 (see also Howard et al., 2009 on land use implications of sustainable energy production in the UK). The Road Map also highlights how harnessing renewables has the potential to create new patterns – and geographical scales – of economic integration, via its recognition of an 'All Islands' approach (Ireland, United Kingdom, Channel Islands, Isle of Man) to the generation and transmission of electricity from low-carbon sources.[1] The UK Government's Department for Energy and Climate Change 2050 Pathways analysis (and 2050 Calculator) – which for the most part adopt a simple national scale of analysis – includes a mapping tool which encourages the public to consider the land requirements and spatial trade-offs for different energy supply technologies and the way different energy technologies can be in competition for the same space (e.g., between rooftop solar PV and solar thermal). In general, as policies like Electricity Market Reform have increasingly recognised and quantified the investment challenges associated with a low carbon transition, so there is increasing interest in *where* that investment will materialise. The goal of a low carbon transition, in other words, is slowly emerging as a question of which geographical futures will be created.

These efforts to map out the potential geographies of a low-carbon economy are welcome but, in our view, are constrained by a limited and somewhat rudimentary conceptualisation of the spatial dimensions of energy transition. The field of human geography – for which space, place and scale are foundational concepts – has developed conceptual tools with which to describe and assess the *spatiality* of socio-economic and political activity (the arrangement of social, economic and political life in geographical space). For example, economic geography developed the notion of the 'space economy' to capture both the locational pattern of economic activities and their inter-linkages at any one point in time, and also the dynamic way in which the practical activities of economy (trade, investment, regulation etc.) produce new spatial configurations and relations (Isard, 1956, Harvey, 1982). The aim of this paper, then, is to unpack the spatiality of the low carbon energy transition by providing a basic conceptual language with which to describe and assess the geographical implications of a transition towards low carbon energy (Massey, 2005). We draw upon the experience of a seminar series we co-convened between 2009 and 2011, as well as our involvement in various other energy research initiatives.[2]

2. Energy transition: From historical concept to geographical framework

The concept of 'energy transition' is now widely used within energy studies and has been incorporated into the national energy policies of some countries. Although its implication of a change in conditions is clear enough, there is no consensus on a desired end state. In parts of the global South, energy transition implies a significant increase in the availability and affordability

[1] Energy 'islands' are also an important issue at the EU scale, where the Baltic States are seen as a particular case of energy isolation that needs to be dealt with by interconnection and cooperation.

[2] These include the ESRC/EPSRC research cluster on *Energy Security in a MultiPolar World*, the ESRC-EPSRC Interdisciplinary Cluster on *Energy Systems, Equity and Vulnerability*, and the UK Energy Research Centre. The seminar series *'Geographies of Energy Transition: security, climate, governance'* was funded by the UK's Economic and Social Research Council (RES-451-26-0692). The five seminars in this series initiated a dialogue between human geography and the interdisciplinary field of energy studies with the aim of (1) building research capacity within human geography on issues of energy transition, energy security and climate change, and the spatial organisation and governance of new energy systems; (2) promoting inter-disciplinary collaboration; and (3) generating new ways of thinking about energy transition as a geographically-constituted process. This paper, written by the convenors of the seminar series, is informed by the discussions that took place over the course of the five seminars. Many of the contributions to the seminar series took the form of empirically-grounded assessments of particular sectors, technologies or regions. The authors have reflected on these contributions to develop in this paper a conceptual language with which to describe and assess the geographical implications of a transition towards low carbon energy.

of modern energy services and, in some particular contexts, this may also mean an increase in carbon intensity (around, for example, increased personal mobility or the switch from household fuel wood to grid electricity) (Bradshaw, 2010). In the 'transition economies' of Central Europe and the former Soviet Union energy transition is framed primarily as a 'liberalisation' of the energy sector with key changes occurring in the structure of ownership and the role of competition (Bouzarovski, 2009). In the UK, energy transition is defined within government policy as movement towards a 'secure, low carbon' future with a target of 80% reduction in CO_2 by 2050. Analyses of the lowest cost way of achieving this goal lead to the conclusion that electricity is likely to assume an increasing role: the UK policy goal is to decarbonise the electricity sector first (40% of electricity from low carbon sources by 2020), and then use electricity more widely to meet the target of 80% reduction in CO_2 emissions by 2050 (Foxon et al., 2008).

Within energy studies, transition is employed analytically to assess major historical shifts in energy systems at national and global scales (Smil 2005, 2010; Podobnik, 2006, Fouquet and Pearson, 1998). Research on historical energy transitions centres on significant shifts in the role of different primary fuels and conversion technologies in the energy mix, such as the transition from wood and water power to coal in the 19th century, or from coal to oil in the twentieth. This work shows how historical energy transitions have been associated with broad social change, such as industrialisation, urbanisation and the growth of the consumer society. A low-carbon energy transition is likely to be as significant – and its social, technological and geographical implications as hard to imagine – as the shift from wood to coal, or the electrification of urban and rural areas in the late 19th century (Jiusto, 2009). Despite this, contemporary work on low-carbon energy transition has paid only very limited attention to questions of scale and space.

A guiding research framework (in Europe) has been the multi-level perspectives approach to socio-technical transitions that emphasises structural innovation in energy systems (Verbong and Geels, 2007; Smith et al., 2010; Grin, 2012). This perspective mobilises geographical *metaphors* – niche, regime and landscape – to provide a contextual account of technological change and understand system innovations over time. While this approach has contributed a great deal to understanding of how transitions can occur, its primary concerns are the unfolding of a temporal process and the identification of factors that cause some niches to evolve, or be incorporated into regimes while others do not. These concerns have tended to circumscribe any formal attention to space, place and geographical scale within conventional transitions theory.

Yet there are good reasons for thinking of transition in geographical terms. First and foremost, energy systems are constituted spatially: the components of the system are embedded in particular settings and the networked nature of the system itself produces geographies of connection, dependency and control. This is most obvious with energy infrastructure – the classic 'choke point' and 'bottleneck' geographies associated with the international shipment of crude oil or the management of electricity distribution grids, for example (Emmerson and Stevens, 2012) – but can also be extended to consider the geopolitical and geo-economic dependencies associated with the multinational ownership of oil, gas and electricity companies. Furthermore, the 'high energy society' that is characteristic of OECD economies (Nye, 1998) – one defined by increasing energy availability at progressively lower unit costs – has given rise to distinctive spatial patterns of economic activity. At the world scale, it has underpinned the increasing separation of production and consumption since the 19th century (Chisholm, 1990). The globalisation of economic activity rests, in part, on falling relative costs for energy in transportation (Dicken, 2011). This is attributable to the increasing availability over time of progressively higher quality energy sources (from coal to oil, or from steam to electricity), increased economies of scale in the production and transport of goods, and the ability to displace (socially, temporally and geographically) many of the social and environmental costs of increased energy abundance. And at regional and urban scales, the price and availability of energy have influenced patterns of urban development and building design. It is well known, for example, "how the geographical pattern of industrialisation in nineteenth century Europe closely coincided with the geological distribution of coal beneath the ground" and such influences are still visible in patterns of urbanisation in contemporary Europe (Strange 1985:191). The strong correlation between economic development (as measured by GDP per capita) and national rates of energy consumption (particularly for electricity) powerfully illustrates how contemporary patterns of economic activity rest on geographies of energy capture and conversion and the ability to displace the environmental costs of energy use over time and space.

Our interest lies in working out the geographical elements of continuity and change associated with energy transition (Coe and Jones, 2010: 10). Delivering energy services at affordable prices but with fewer greenhouse gas emissions will require massive investment to re-construct the geographies of producing, living, and working with energy (International Energy Agency, 2008; Mernier, 2007). Meeting the challenges of climate change and energy security is, therefore, fundamentally a geographical project: it not only requires societies to commit massive investment to redesign infrastructure, buildings and equipment, but also to make choices from a range of possible spatial solutions and scales of governance.

3. Unpacking space: Geographical components of transition

What do we mean by 'geographies of energy transition'? By *geographies* we mean at least two things:[3] first, the distribution of different energy-related activities across a particular space – such as the UK – and the underlying processes that give rise to these patterns; and second, the geographical connections and interactions between that space and other spaces (i.e.. the UK's position in a wider political economy of states, transnational firms, international agreements, and non-governmental organisations). This second point is particularly important: the energy system of the UK is remarkably open to these non-domestic influences via a combination of European and international commitments (UNFCCC), European energy market liberalisation and the EU Emissions Trading Scheme, the ownership of the 'big six' utilities (as well as major oil companies) and, notwithstanding the UK's own coal, oil and gas resources, the high (and projected to rise) penetration of imports in the UK's primary energy mix. The UK has gone from being a net energy exporter in 2000 to importing 28% of its hydrocarbon needs in 2010, with coal import dependence reaching 51% and gas import dependence 38% (Department of Energy and Climate Change (DECC), 2011a, 11).

The remainder of this section takes this process of unpacking space a step further by outlining six geographical components of transition. The examples provided are illustrative and our discussion is not intended to be comprehensive. It is the sense of *contending* geographical futures at the heart of low-carbon transition that we seek to capture here, rather than a definitive

[3] Following Coe and Jones (2010).

Table 1
Potential changes in the location of key energy system components associated with a low-carbon energy transition.

Component of energy system	Nature of locational change
Primary energy sources	• Diversification into non-conventional fuels (biofuels, oil sands and shale gas) may reduce import dependency and shorten distances between location of energy capture/extraction and consumption; however, may also lead to expansion in the geographical reach of energy systems in other instances (e.g., biofuels, conventional fossil, uranium).
Fossil fuel power plants	• coal-fired power plants may remain a key component of energy system, but logic of coalfield location increasingly offset by costs associated with transporting CO_2 from point of capture to point of storage (under CCS); • cost considerations move preferred location of new plants closer to CO_2 storage sites (in the UK, this would mean the coast of the North Sea)
Low-carbon electricity generation	• installation of large, low-carbon electricity generating capacity (e.g., upland wind, offshore wind/wave, north African solar, coastal nuclear) focused on resource locations remote from markets; • overall geographical dispersal of electricity generating capacity, reflecting both lower energy densities of renewables and need to address the intermittency of flow resources like wind and solar
Electricity and gas transmission systems	• increased electricity transmission capacity overall, particularly from north to south in scenarios with high levels of wind and/or CCS, and greater connectivity of individual locations • increased LNG in the short term and alternative long term futures, including rapid decline and substitution of natural gas by biogas
Consumers	• increasingly dispersed, with energy demand increasingly marginal to value creation; increased awareness of carbon content • small-scale generation opportunities blur distinctions between electricity producers/consumers in some settings • conventional investments in supply augmentation and distribution supplemented with co-ordinated expenditures on energy efficiency and demand reduction (mainly in urban settings)

statement of what the geographical dimensions will be. Our aim is to provide a conceptual framework for unpacking the spatial elements of transition in order to think systematically about what transition might mean for the spatial organisation of energy systems—and for economic activity more generally.

3.1. *Location (absolute and relative)*

Thinking about the geographies of energy transition begins with the basic spatial concept of location. ‘Location’ here is both an absolute characteristic (latitude and longitude) *and* a relative one, describing the ‘relational proximity’ of one element in the system to another. While absolute location is fixed and unchanging, relative location can be highly dynamic: the application of fossil energies to locomotion (railways, steamships) in the mid-19th century, for example, dramatically changed the relational proximity of cities served by these expanding networks, bringing them ‘closer together’ while simultaneously increasing the relative distance between them and other places that were not served by rail or steamship line. With the UK becoming a net importer of fossil fuels over the past decade, so the country’s relative location has changed. The recent upsurge of policy interest in ‘gas security’ in the UK, for example, reflects a repositioning of the country in the global political economy of gas as a result of domestic offshore depletion, perceived vulnerability at the ‘end’ of European pipelines from Russia and Central Asia, and the construction of LNG import terminals to increase the relative proximity of the UK market to alternative gas supplies in North Africa, West Africa and the Middle East. The transformation of relative location is also central to contemporary debates over aviation and high-speed rail: advocates celebrate their capacity for decreasing travel time and increasing the frequency and intensity of interactions between places, while critics point to energy consumption (and carbon emissions) associated with higher speeds.

Brief examples like these serve to indicate how the current, carbon-intensive energy system (fossil fuel extraction, electricity generation, waste disposal) has a particular *spatiality*—that is, its interlinked elements occupy locations in space. The ‘logic’ of these contemporary locations is related to historical considerations and, in large part, they reflect an energy system designed to deliver abundant, reliable supplies at low cost to consumers without regard for carbon constraints. The decarbonisation agenda, combined with significant shifts in the structure of the domestic economy associated with de-industrialisation and the rise of the consumer-society, has thrown many of these locational considerations into question. Within economic production there has been a relative shift from industry to services: industrial output has grown only 30% in the UK over the last 40 years, while the economy as a whole has grown by 150%. The UK’s energy ratio (the relationship between the growth of GDP and the growth of energy consumption has declined 2% per year on average since 1970 (DECC, 2011b, 164).

Less noticed, but equally important, energy use has shifted from being predominantly associated with economic production to consumption: approximately 50% of UK energy use is now in homes and personal transport (largely private cars). Much energy use in the service sector has a similar character: it is highly distributed (individually and at small scale), and marginal to the process of production. While absolute growth in demand in these sectors has now ended in the UK, most energy futures foresee a continuing relative shift from large scale centralised consumption to a distributed energy consuming future.

We can also consider the location of other elements of the energy system beyond demand. Implementation of a low-carbon energy transition, such as outlined in the UK Government’s Low Carbon Transition Plan (2009), will involve several significant shifts in the location of key components of the contemporary energy system (Table 1). The decarbonisation of the power sector, for example, may be associated with shifts in the nature and location of primary energy sources as well as the location of new build fossil fuel power plants.[4] Similarly, programmes like the Green Deal imply a shift downstream in the locus of investment in the energy system towards improving consumption efficiencies in the housing and commercial sectors.

Policies designed to achieve a low-carbon energy transition will also have an impact on the spatial organisation of local, regional and global economies. The globalisation of manufacturing activity since

[4] There are also some locational continuities: in the specific context of UK decarbonisation, for example, any new nuclear build will take place at existing sites rather than at greenfield locations.

the mid-twentieth century has been driven by cheap fossil-fuel energy sources and the consequent falling cost of transportation (Dicken, 2011). The current global distribution of economic activity – the international spatial division of labour – is a function of an historically-specific relationship between energy, environment and economic production. The remarkable growth of world trade since 1950 – more than four times faster than world economic output – occurred under conditions where the energy costs of production and transportation were low (relative to total costs) for many goods and where the environmental effects of industrial capitalism have been largely external to the decision-making of firms and states. The divergent trends in greenhouse gas emissions between developed countries (stable) and developing economies (increasing) is due in no small part to international trade flows arising out of global shifts in manufacturing (Peters et al., 2011). The effect has been most marked in the last decade with the rise of manufacturing in China effectively resulting in relocation of a significant fraction of developed world industrial energy demand to a region with a higher carbon intensity of production.

Any significant increase in the cost of energy and/or carbon will reassert the historic 'friction of distance,' with significant implications for the geographical distribution of economic activity (Rubin 2009). Together the 'end of cheap oil' and the emergence of carbon pricing have the potential to re-draw the map of economic activity in some interesting ways—just as previous revolutions in the cost and availability of energy to society produced distinctive geographical forms. There is already some evidence that a process of 'deglobalisation' may be underway in parts of the food sector, in response to rising fuel prices and a range of consumer concerns that include 'food miles' and a desire to support 'local' production (Bailey and Wilson, 2009; North, 2010). Our broader point here is the need to understand how the locational decisions that underpin contemporary patterns of international trade – and, more generally, the global map of economic activity – are premised on abundant and low-cost fossil fuels.

3.2. Landscape

Whereas location refers to a point in absolute or relative space, 'landscape' describes the assemblage of natural and cultural features across a broad space and the history of their production and interaction. We use the term 'energy landscape' in the same way as implied by an 'economic' or an 'urban' landscape: that is, to describe the constellation of activities and socio-technical linkages associated with energy capture, conversion, distribution and consumption. For geographers, material landscapes – from oil fields, to wind farms, to urban settlements – are the product of social processes and the outcomes of conflict and negotiation among different social groups. The transition towards a low-carbon economy will require the re-appraisal of the form, function and value of some contemporary and familiar landscapes. On the one hand, landscapes dedicated to fossil fuel extraction or methane-producing livestock production, or premised on the combustion of liquid fuels, are now scrutinised by policy makers for ways in which their carbon-intensive character might be foreclosed, mitigated or offset. On the other, landscape forms that sequester carbon or which provide opportunities for the generation of 'green power' gain a new source of potential value and are targeted for commercial development. These include both remote rural landscapes, such as uplands (for wind) and narrow sea passages (for tidal stream), and urban environments (for building mounted photovoltaics and energy from waste). The twin goals of decarbonisation and energy security mean that "energy will again become a major driver in land cover change" (Howard et al., 2009: S284). In this way low-carbon transition policies are productive of new energy landscapes, while 'carbon control' has become a critical metric of political and economic governance at urban, regional and international scales (While et al., 2010: 77; Bridge, 2011).

Because potential low-carbon resources are already embedded in existing geographical settings, harnessing them to the objectives of low-carbon energy transition involves conversion or modification of current practices and systems of valuation. Existing social attachments sometimes present strikingly different systems of value compared to energy prices or tons of CO_2 foregone—for example, tidal zones valued for their contribution to ecological and biodiversity objectives. Some of the fiercest contemporary struggles around energy transition centre on the development of lower-carbon energy technologies such as wind, tidal and hydro, as well as the creation of new reservoirs and depositories (for carbon and nuclear waste) to better manage the downstream impacts of conventional fuels. For many people, then, 'low carbon energy transition' is experienced as the *transformation of landscape*—i.e., the extension of industrial and extractive components of the energy system into places and communities that previously were unaffected. It is for this reason that "landscape has become a key arena in the debate on energy policy" (Nadai and Van der Horst, 2010: 143; see also Pasqualetti, 2011).

Landscape not only refers to the material features of a particular setting, but also implies the cultural evaluations and emotional attachments that people load onto these material forms. The geographical notion of 'topophilia' (love of place) can be helpful here, as it describes the attachments to place that people form with particular material forms and, in western societies, the dominance of the visual aesthetic (the optic of 'beauty') as a way of appreciating landscape (Tuan, 1974; Nadai and Van der Horst, 2010). Many of these cultural constructs are built into planning regulations and into law – via land use designations such as Areas of Outstanding Natural Beauty and rules on visual intrusion, for example – in ways that constrain the deployment of low-carbon technologies in some settings while simultaneously enabling them in others (which lack such designation). Understanding place attachment and the emotional responses that people can have to energy landscapes provides a more productive approach than simplistic assertions of NIMBY-ISM for analysing conflicts over energy landscapes (Devine-Wright 2005, 2011).

Popular debate may have been excessively occupied with a narrow range of siting controversies associated with wind turbines and high voltage electricity transmission pylons, yet the potential landscape transformations associated with a low-carbon transition extend far more widely. They include, for example, the adoption of annual and short-rotation energy crops in agriculture (alongside more traditional herbaceous crops) in response to policy initiatives like the EU Biofuels Directive and the UK's Renewables Obligation. The role that new fuel crops – like Miscanthus, Willow or Poplar – can play in multifunctional agricultural landscapes is currently unclear, although concern has been raised at the potential for large-scale land conversion and energy commodity production at the expense of other, 'post-productivist' goals like watershed protection and biodiversity conservation (Upham et al., 2011). The growing OECD-demand for biomass energy means that policy objectives in these countries are driving land transformations beyond their borders, in countries of the global South where net primary productivity is high and where political conditions are conducive to investment (McQueen and Korhaliller, 2011). In these countries, new industrial demands for exported biomass (e.g., as biomass pellets for co-firing in electricity production) intersect with long-established uses of fuelwood (and other forms of biomass) for heating and cooking. This can create opportunities for economic development, although these opportunities often work with (rather than against) the grain of existing inequalities. By drawing attention to the livelihood strategies associated with particular configurations of plants and people, 'landscape' provides a way to examine the social implications of the new energy landscapes associated with low carbon transition.

A low-carbon energy transition has significant implications for landscape at the urban scale too. Increased attention to energy efficiency and carbon management at the urban scale mean that long-standing assumptions about city spatial form, the density of settlement, building design and choice of materials are being re-considered (Lovell, 2007; Bulkeley et al., 2011; Hodson and Marvin, forthcoming). At the level of everyday experience, one of the most visible components of a low-carbon, urban landscape will be changes in the space allocated to different transport systems—specifically, a reduction in the dominance of the car within the urban landscape and the growth of mass transport and other non-car alternatives (including cycle lanes and pedestrianisation). In general then, the concept of 'landscape' is useful for understanding energy transition because it draws attention to the interaction of natural, technical and cultural phenomena in a geographical setting, and how these particular assemblages vary over space and time. This heterogeneity of landscape is significant for policy: it is both a source of novelty and experimentation (different places can do things differently) and a cause of uncertainty in outcomes (existing conditions refract standard policies into a range of responses) (see Nadai and Van der Horst, 2010). While many of the manufactured landscapes of fossil fuel capitalism have become 'normalised' over time (the coal mine and factory-city, the gas station and suburban strip-mall), many of the potential landscapes associated with a low-carbon transition are highly contested, raising questions about which landscapes should be made, and who landscapes are for. In this way, a rather prosaic concept – landscape – can be a powerful tool for thinking through some of the most challenging issues associated with low-carbon energy transition.

3.3. *Territoriality*

How social and political power are organised and exercised over space is described by human geographers as 'territoriality' (Brenner et al., 2003). The concept applies to the geographical strategies of partition and integration employed by economic and political actors (states, firms) in the exercise of authority and/or commercial power. All infrastructure systems for energy capture, transmission and distribution are spatially constituted, but they have been territorialized in different ways over time. In the electricity sector, for example, a series of isolated 'islands of power' have been replaced over time by integrated national and continental scale grid systems (Platt, 1991, Nye, 1998). Similar trends have been observed in gas grids with a move from city-scale coal gas production to national, and now continental scale, grids. While these might simply be described as scaling up or integration, a focus on the way energy systems are *territorialized* draws attention to the different scales and arenas of political action that govern energy systems because of the way they are spatially constituted (Hughes, 1993).

Historically, the re-territorialisation of electricity at the scale of the nation – the replacement of localised municipal systems with a national grid – has been a major political project, as well as an economic one. This is not simply to recognise that such transformational projects required political will: rather, that the re-scaling of energy infrastructure and the diffusion of particular technologies have also been integral to political projects in their broadest sense, such as the modernisation of the nation and the making of the modern citizen. Accounts of the territorial expansion of hydropower (White, 1996; Byrne and Toly, 2006), nuclear (Hecht, 1998; Jasanoff and Kim, 2009), and hydrocarbon energy sources (Bouzarovski and Bassin, 2011) illustrate how the natural resources and technologies of energy systems can influence the rise of particular group affiliations at the level of nation states. A critical point here is that the spatial diffusion of energy technologies is culturally contingent: how new energy technologies spread across space often depends on how these technologies (and the natural resources upon which they are deployed) are embedded in (national) systems of signification and cultural routines. This is significant for policy because the deployment and geographical diffusion of new and more efficient technologies – from electricity generation based on renewables, to electric cars and household smart meters – has a central role in most policy accounts of low-carbon energy transition.

Territoriality is particularly useful for thinking through the contemporary challenges and opportunities of low-carbon transition in the UK because of its focus on the interaction of political power and bounded space, and because the territorialisation of the UK energy system is an unsettled project that is on-going and contested. The UK's energy system is being re-territorialised in the context of EU policies on the liberalisation of energy markets and the EU's desire to implement a European energy strategy: in simple terms, energy landscapes in the UK increasingly depend on decisions made outside the UK—in Brussels, or in the headquarters of international energy companies. At the same time, there is an increasing recognition of the significant role that cities and urban infrastructural networks play in energy consumption and the emission of greenhouse gases and that, as a consequence, cities are potentially important sites for political action around energy transition (Bulkeley et al., 2011; Hodson and Marvin, forthcoming, While et al., 2010). Several initiatives – both part of formal government policy and outside it (e.g., Transition Towns) – seek strategically to territorialize low-carbon transition at the urban scale. And the C40 Cities Group seeks to circumvent the gridlock in the inter-governmental climate process by a global alliance of city initiatives. Other territorialisations of low-carbon energy – such as the ambition articulated by some political leaders in Scotland to be the ''Saudi Arabia of renewables'' – speak directly to the way energy projects can do political work (in this case as part of a broader strategy of political independence). More generally, the concept of competing or alternative territorialisations is helpful for understanding Europe as a contested 'geo-energy space', in which a series of territorial legacies (including the 'imperial' energy infrastructures of the FSU in eastern Europe, and a diverse set of national energy systems in western Europe), the liberalisation agenda of the Energy Charter and an emergent regional energy strategy (exemplified by the EU-Russia Energy Dialogue, for example) are all in contention (Mañé-Estrada, 2006; Correljé and Linde, 2006; Bouzarovski, 2009).

Territoriality is also valuable for thinking about the way in which energy production networks are organised geographically in order to generate and capture value. The territoriality of energy infrastructure networks can be assessed in terms of their *contiguity* (dispersion/density) and *connectivity* (Hess, 2004). Historical assessments of large infrastructural systems draw a distinction between the 'city' and the 'network' as two contrasting spatial forms (Coutard, 1999): while both connectivity and contiguity are high in the former, the latter have high connectivity but low contiguity (Table 2). However, to these we can add a third dimension of territoriality: that of *centralisation*, which describes the degree to which critical capacity and supply decisions are centralised and co-ordinated by a single body. The degree to which power and authority over a network are centralised or devolved can be significant for its capacity to contribute to the goals of a low carbon transition. In the case of the UK's 'big six'

Table 2
Infrastructural networks for energy.

Illustrative spatial form	Contiguity	Connectivity	Centralisation of capacity and supply decisions
District heating system	High (i.e., a dense geographical form)	High (many points of connection)	High/Low (centralised within each district heating facility; although fragmented at national scale)
National electricity grid (prior to unbundling)	Low (i.e., a dispersed geographical form)	High	High
Continental gas pipeline	Low	Low (few points of connection)	High
National electricity grid (with multiple autonomous suppliers)	Low	High	Low
Off-grid 'autarkic' domestic electricity generation	High	Low	High/Low (centralised within each building; although very fragmented at national scale)

energy companies, for example, analysis suggests the centralised structure of these organisations constrains their ability to deliver both decentralised renewable investment (Mitchell, 2007) and the demand-side activity that is a key piece of UK policy on improving the efficiency of gas and electricity consumption in households (Eyre, 2010), because the customer-facing components of these large, international firms are, in fact, downstream appendages of integrated energy companies where the major profit centres are upstream.

The simple typology of Table 2 highlights some of the contending spatial forms that are at work in the evolution of a low carbon energy system. A strategy that targets flow resources like wind or solar for the generation of electricity requires a dispersed strategy of generation, in order to manage the relatively low power densities and intermittency associated with these resources (diurnal and seasonal variation in insolation rates or the reliability of wind). These dispersed sites can be operated 'off-grid' (or as part of regionally-contained grid systems) or they can be networked nationally. The question of centralisation, however, is independent of the infrastructural configuration: a series of dispersed, off-grid sites may be owned and managed by a single company, while a highly-networked model may be comprised of independent suppliers. Coutard and Rutherford (2010) highlight a number of alternative models associated with low-carbon transition that challenge the modern large-scale network, including off-grid development, local loop-closing systems, strategies for the preservation of unequipped spaces, and support for feed-in to networks by independent suppliers. Addressing the challenge of universal access to modern energy services, for example, will involve a combination of grid and off-grid solutions (World Bank, 2010).

3.4. *Spatial differentiation and uneven development*

A geographical perspective on energy transition is one attuned to spatial variation and, more particularly, the production of geographical differences. Taken together, the locations, landscapes and territorialisations associated with a low-carbon energy transition will generate new patterns of uneven development. Understanding this variation and difference is important. For geographers, spatial differentiation is understood not as a static mosaic of inherent difference, but as a process of simultaneous equalisation and differentiation—the "ongoing production of differences between places" (Crang, 1996).

It is clear that some of the processes associated with energy transition will promote spatial convergence: the normalisation of appliance standards for energy efficiency, for example, means that geographical variation in the energy efficiency of particular appliances will be reduced over time and, in some instances, eliminated. Growing energy trade, technological diffusion, and standardisation of consumption norms are also expected to drive a convergence in the energy intensity of GDP over time (BP, 2012, 19). Other aspects of energy transition, however, will enhance the degree of difference between places: to the extent that building regulations are increasingly attuned to local climatic conditions, for example, building codes are likely to favour a return to vernacular forms of architecture which feature passive heating and cooling solutions. Similarly, because the capacity to take up different renewable energy technologies is closely linked to geographical conditions – as well as being mediated by prevailing conceptions of landscape quality – the regional uptake of renewables is likely to exhibit wide spatial variation: Cowell (2010) illustrates the complex and uneven pattern of wind farm development within Wales, for example. However, much contemporary discussion of energy transition is either aspatial or based on implicit assumptions about spatial convergence, with comparatively little attention to how policy proposals for the low-carbon economy will influence current patterns of uneven development.

The process of spatial differentiation – or the 'production of geographical difference' – is not limited to energy systems themselves, but extends to their implications for patterns of economic growth and development. The innovations associated with low carbon transition are, like many other technologies, found in geographically-defined clusters. There are plenty of examples of places around the world promoting themselves as a hub for low-carbon development, where regional economic fortunes are hitched to becoming an important global locus of innovation for low carbon energy, or as an export platform for low-carbon power (such as the Desertec initiative to use the abundant solar resource in North Africa to supply Europe via an extended international electricity grid, or proposals for biomass exports from the tropics). Spatial differentiation consequent to a low-carbon transition also extends to financial flows associated with carbon services (such as carbon offsetting via the Clean Development Mechanism or payments under REDD) and to the implications of transition for economies predicated on the production or conversion of fossil fuels. The broader point here is the potential of a low carbon transition to re-work established patterns of 'core' and 'periphery' at multiple scales, and the need to conceptualise low carbon transition as a simultaneous process of geographical equalization and differentiation that has the potential to produce new patterns of uneven development. And it is, of course, precisely because of this potential to create new geographies of winners and losers that low-carbon transition faces opposition from those with a vested interest in the status quo.

3.5. *Scaling*

Scale here refers to the material size and areal extent of phenomena. It describes the different geographical forms in which different energy technologies can be deployed—from micro-scale applications of wind turbines and solar PV at the household scale to macro-scale deployments across entire landscapes, for example. It can also describe the varying geographical reach of different political structures – such as local, regional and national government; and forms of economic organisation – differentiating, for example, a businesses operating in only one locality from a transnational corporation. Because the scale at which energy systems are organised and governed is not pre-ordained and arises instead as a product of economic and political decisions, it useful to adopt the verb (scaling) rather the noun. Scaling highlights not only the *emergent* character of geographical scale in the context of energy systems; it also emphasises the range of choices that exist in how low carbon energy systems might be scaled.

The question of scale is particularly significant for renewable energy technologies (such as biomass, solar PV, solar heat and wind) which, more than other energy technologies, can be deployed across a very wide range of material sizes—what Walker and Cass (2007) term the 'hypersizeability' of renewable energy hardware. The significant point is that "each of these hardwares, when implemented at different sizes, has different relational qualities of physical presence, connection to other physical infrastructure (buildings in particular), degrees of mobility and potential for environmental impact and disturbance" (Walker and Cass, 2007: 460). The social meaning of renewable energy technologies, therefore, varies considerably depending on the geographical scale of their deployment as well as the manner or mode in which they are deployed (public utility, private supplier, community etc). While European and UK energy policies establish clear targets for renewables, they have very little to say on the scalar configuration of their deployment. There are, however, "profound social and geographical implications embedded within emerging patterns of renewable energy utilisation" that a focus on scaling is beginning to tease out (Walker and Cass, 2007: 458). This plays out in policy decisions about Feed-in tariffs differentiated by project size, which have implications for the cost effectiveness of different scales, e.g., distributed versus centralised solar PV, and therefore for different landscapes.

Assumptions about scale pervade energy policy. While these often go unchallenged, they nonetheless can have significant consequences. Energy policy as conceived by most public policy makers in economies like the UK (as opposed to the wider set of activities and actors that constitute energy governance), is made at the nexus of central Government and the oligopolies that dominate national energy supply —the international oil industry and (largely trans-national) electricity supply companies. This has two implications. The first is that the decentralised parts of the energy system – distributed supply, end use technology and the determinants of demand itself – are systematically marginalised in policy making. Although, self-evidently, (largely distributed) demand is quantitatively as important as (largely centralised) supply, the policy levers and actors immediately available to national policy makers operate predominantly at the national scale. There is therefore a tendency to treat decentralised actors as remote, unpredictable or even capricious, especially when they 'fail' to behave in accordance with the preferred models of national decision-makers. Hence the preference for 'reliable', centralised, supply side solutions. Alternative futures, with more reliance on energy demand reduction require smaller scale energy systems (Eyre et al., 2010).

The second implication is that even policy objectives relating to distributed supply, energy efficiency and energy demand have increasingly been delivered through obligations on the dominant supply companies, notably the Renewables Obligation and the Carbon Emissions Reduction Commitment. This choice is because these companies are key actors in the recognised system, rather than necessarily the most effective actors to deliver decentralised activity. Indeed, the evidence would tend to indicate that trans-national energy companies are very unlikely to be the best at, for example, securing support from local communities for wind farms (Walker et al., 2007) or undertaking detailed building refurbishment (Killip, 2011). The centralisation of policy arguably therefore results in ineffective policy when the object of 'delivery' is widely distributed.

The alternative, devolving energy policy more widely, would be a major change for economies like the UK.[5] Local stakeholders, notably local government, have been marginalised from energy governance since the post-war nationalisation of utilities. They have little capacity to engage effectively in energy policy debates, no seat at the tables where energy policy is made and often little involvement with programme delivery. There has been a rise in interest in "carbon" in some of the more progressive local authorities and some high profile initiatives involving major cities (While et al., 2010). However, there is no evidence that these have had any significant impact. Centralised governance largely represents a hangover from a period when distributed issues were perceived as less central to energy policy challenges. However, neither recent nor planned changes offer much prospect of change. Although the reform of energy markets in the 1990s (privatisation, liberalisation and unbundling) might seem to have been a step in that direction through breaking the dominant role of the state, in practice the system that has developed is different largely in the balance of public and private power, but is still highly centralised.

Energy is typically scaled as a national issue because no government wants to risk the domestic political consequences of a failure in supply: in countries like the UK, where reliable energy services have become the norm, 'keeping the lights on' is a powerful political imperative (Stevens, 2010). Current policy initiatives around 'energy security' exemplify this default to the national scale and the privileging of some socio-technical configurations and material sites over others. Scaled differently, however, it is possible to see how problems such as energy poverty or domestic warmth deprivation are also issues of energy security, as both endanger human security at the level of the household (Bouzarovski et al., 2012). As an analytical lens, scaling can illuminate significant questions about who is affected, who has the capacity for action, and where the boundaries of responsibility lie. It can, therefore, be extremely useful for highlighting capability gaps within policy (such as where responsibility exists without capacity, or where an affected group has limited capacity for action) and for opening up alternatives that illuminate the scalar assumptions upon which current initiatives rest.

3.6. *Spatial embeddedness and path dependency*

The final concept we introduce here is that of spatial embeddedness (and path dependency) as obstacles to a low-carbon transition. In doing so, we draw inspiration from multi-level transition theory's comparison of niche and incumbent energy systems. However, we take this a step further to recognise how 'niche' and 'incumbency' are an expression of the different degrees to which energy systems are geographically embedded. By embeddedness we mean both the sunk costs of capital investment (represented by the built environment and the infrastructures of energy capture, conversion and consumption), and the place-based cultures of consumption that surround certain energy technologies (expressed, for example, in expectations and

[5] In many countries in the global South, by contrast, a lack of state capacity and limited private investment mean that localised solutions are often the only ones available. The challenge in these settings is frequently one of scaling up.

norms about the cost and reliability of supply, or the social practices associated with energy consumption). Spatial embeddedness, then, encompasses the economic, material and cultural aspects of energy systems. This can be seen with particular clarity in the context of automobility, and the difficulty of persuading people to give up their car in favour of other forms of mobility (Paterson, 2007). The degree to which fossil fuel consumption is 'built into' the urban landscape (in the morphology of cities, the allocation of space to the car and the systematic under-provision of alternatives, and via norms of car ownership) demonstrates wide geographical variation. Spatial lock-in can be a major challenge to those seeking to achieve a low carbon transition via encouraging consumer-drivers to switch transport modes.

In other settings, however – such as parts of the developing world – historically limited energy service provision means fossil fuels have not become embedded in the same way. Limited lock-in around fossil fuels can create opportunities for the rapid uptake of renewables. Places where state-led development has conspicuously failed to extend centralised electricity services via comprehensive rural electrification, for example, can provide opportunities for the deployment of small-scale photovoltaics (in much the same way that lack of fixed line telephone service has created opportunities for rapid penetration of mobiles) (Ulsrud et al., 2011).

What is clear is that the normative vision of a 'low carbon transition' that guides policy in many OECD countries – where transition involves challenging an incumbent high-carbon system – can be achieved in a number of quite different ways. While a greater role for highly distributed actors is widely discussed (as set out above), this is neither inevitable nor the only form of low carbon transition. Other discourses focus on using very large sources of alternative energy to replace the existing dominant fossil fuel sources. There is, of course, a legitimate normative debate about the extent to which such a solution is "better" or "worse" than distributed alternatives. We do not seek to address that here. We simply note that the governance implications of highly distributed and centralised systems are quite different, with a much bigger role for effective international agreements and lower reliance on sub-national actors in the case of the latter. And whilst it is quite possible to design a technical system with aspects of both approaches, the governance implications of the two systems are so different that such a "mix and match' approach may not be possible. An early move in either direction may 'lock out' the other option, not because it is innately less desirable, but rather because the institutional arrangements may make the alternative inoperable.

4. Conclusion: Space and the low-carbon economy

Convergent research interests within energy studies and human geography provide an opportunity to critically examine the spatiality of energy transition. We have outlined the nature of this shared interest and how it illuminates issues of relevance to contemporary energy and climate policy. Our call is for future research to capitalise on this convergence by paying greater attention to the geographies of a low-carbon energy transition. Recasting transition as geographical process changes the questions that become important for researchers to ask. Viewed through the lens of time, key questions about transition include the different temporalities of technological and policy innovation, the rates at which particular energy technologies may be mainstreamed, or the evolution of consumption behaviour. By contrast, a geographical perspective on transition foregrounds questions about *spatial difference* (and the co-existence of multiple transition pathways and possibilities); *relations of position and connection* (as illustrated, for example, by the simultaneous processes of integration and fragmentation associated with new energy infrastructure); and *spatial configuration and scales of organisation* (for example, the durability of national energy systems). Understanding the geographies of a low carbon energy transition, then, is about more than mapping the consequences of policy, or understanding the implications of different policy options for particular places (important as these are). Instead, we argue, a goal for future research should be to understand how energy transitions are *spatially-constituted*.

Understanding transition as a geographically-constituted process – rather than as a process that affects places – has a number of significant implications for policy. First, spatial difference and the fundamentally uneven nature of spatial interactions are both potentially disruptive to policy because they complicate many its assumptions: understanding the way these interactions and interrelations can enable or frustrate policy goals is therefore of practical value. Second, space is a necessary condition for the possibility of multiple, co-existing energy pathways and, therefore, an important source of variety and experimentation: there are significant opportunities, therefore, for understanding the relationship between different trajectories of energy transition and the geographical conditions from which they emerge (Massey, 2005). Third, it highlights how implementing a low-carbon economy will be a simultaneously creative and destructive process that significantly changes how different places are related to each other, economically, politically and even culturally, and at a range of different scales.

Our purpose in this paper has been to introduce a basic conceptual language for unpacking the 'spatial' components of energy transition. In focussing on how transition is geographically constituted we are neither denying the importance of other dimensions nor insisting on the primacy of the spatial. Rather our more modest goal has been to provide a conceptual language for systematically working through the spatialities of energy transition. The six components we have identified are entry points rather than end points: they provide a basic conceptual tool kit with which to develop richer understandings of space and spatial change than are characteristic of current policy approaches to energy transition. Our examples indicate how the geographies of the low-carbon economy are not yet determined and that a range of divergent – and contending – potential geographical futures are in play. More attention to the spatialities of a low-carbon economy can help us better understand what living in a low-carbon economy will be like. They also provide a way to help evaluate the choices and pathways available.

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