Renewable energy innovation systems at the regional level: a conceptual framework to address materiality and spatial scale

Carla De Laurentis, Peter Pearson and Malcolm Eames
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Abstract

Recent contributions have provided theoretical and empirical evidence that a spatial perspective on sustainability transitions is meaningful. The paper contends that, despite these contributions, there is still a lack of understanding of the importance of the regional context – understood in terms of the physical geography of resource occurrence and the natural environment as a source of competitive regional advantage and path dependence. This paper critically reviews recent research on sustainability transitions, innovation studies and geography, and theoretically speculates how a deeper engagement with the concepts of materiality and physical properties of a resource could enrich our understanding of the spatial patterning, distribution and dynamics of low carbon, specifically renewable energy, innovation systems.

Key Words: transition studies, territorial innovation systems, technological innovation systems, low carbon innovation, geographies of transition, natural and built environment

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1. Introduction

In recent years, a growing consensus has emerged around the need for sustainability transitions, including transitions towards low carbon renewable energy (Geels, 2002, 2004; Kemp and Rotmans, 2005; Smith et al., 2010) to be conceptualised at different spatial scales. While earlier studies of socio-technical transitions have been criticised for adopting a pervasive ‘methodological nationalism’ (Späth and Rohracher, 2012), a number of contributions have provided theoretical enhancement, empirical evidence and illustrations that a spatial perspective on sustainability transitions is meaningful. This generated an increased interest and a research agenda on the role of geographical thinking and perspectives in sustainability transitions, including several empirical studies and two special issues on the topic (EIST (2015); European Planning Studies (2012); for a review of the recent literature see Hansen and Coenen (2015)). It is increasingly accepted, therefore, that if the prospect of change in systems of energy provision is to be fully understood, then it is vital to understand how energy systems are constituted spatially (Bridge et al., 2013).

This paper addresses a further issue that has not yet been covered by research in the geography of transitions area, which is the issue of materiality. In contrast to much of the literature on innovation and systems innovation, the argument presented in this paper, foregrounds the importance and role of natural resources and the issue of materiality in helping to explain the uneven processes of low carbon renewable energy (RE) innovation. The material underpinning of the economic, social and political geographies of resource flows can also help spur a renewed debate about the relationships between innovation processes (as they occur at different spatial levels that interact to shape the generation, application and proliferation of renewable energy technologies) and the availability of natural resources and their physical and geographical occurrence.

While the point of departure is the importance of resource availability in policy and practice debates, the intention is not to over emphasise material explanation, following Bridge (2008: 411) who highlights concerns around ‘the conventional claim that natural resources abundance can be converted into a long lasting form of regional advantage’. Nonetheless, this work suggests that there is a need to be attentive to the socially constructed yet biophysical character of nature. The issue of materiality, and how resources can be both materially manipulated and socially constructed, can prove to be valuable in understanding innovation processes and hence enriching the understanding of the spatial pattering, distribution and dynamics of low carbon renewable energy innovation systems.
In this sense, materiality helps us explain how natural resources are both naturally endowed (the influence that they exert vis-à-vis their physical properties and their geographical recurrence) and socially induced (e.g. recognising how a diversity of actors can construct and manipulate nature and create value). The literature on non-renewable resources, especially on oil and gas exploitation, has acknowledged and addressed the issue of materiality (Bouzarovski and Bassin, 2011; Bridge, 2004, 2009; Kaup, 2008, 2014) in ways that the literatures on renewable resources have not. Drawing parallels with the former, it can be argued that renewable natural resources are both i) confined within a particular physical territory and ii) socially and politically constructed by various networks of actors at different scales. What follows seeks to address the way in which the physical characteristics of resources influence RE systems at different spatial scale. The paper provides a framework that puts forward the region as a key spatial and governance level in which materiality and scale coalesce. As the paper develops, it becomes clear that researching low carbon RE innovation requires a more focussed attention on the role that geographical location- and the materiality- of renewable resources play. Adopting the regional lens can offer, therefore, an opportunity to unfold the way in which materiality influences institutions, governance and firm decision making at the regional and other levels.

The paper is structured as follows. The first part of the paper situates the paper within the relevant bodies of literature, starting from a brief review of the growing field of the geography of transitions and its attention to the spatial and relational approaches to scale and how these have been embedded in the systems innovation literatures (TIS and MLP) (section 1). The paper then turns its attention to resource geography (section 2). In doing so, we highlight the importance of materiality in analysing the geography of RE (section 3). Section 4 outlines how the materiality dimension influences networks and mitigates processes between different scales as well as influencing institutional, economic and governance dimensions at the regional scale. We then present a conceptual framework that foregrounds the importance of materiality in RE innovation (section 5), before concluding with a call for further interdisciplinary research and empirical investigation building upon the paper’s insights.

2. The geography of transitions: a brief review

In this section, selected theoretical insights from the geography of transitions literature are examined (for a comprehensive review of the emerging field see Hansen and Coenen (2015)). Recent developments in this field show a significant amount of theoretical and conceptual overlap with economic geography. The attention, in this section, therefore, shifts
between the two literatures. This brief review serves as an entrance point to highlight the contribution that the paper seeks to make in addressing deficiencies—vis-à-vis the importance of materiality—in the current geography of transitions literature.

The geography of transitions field grew up with the dissatisfaction on the way in which early contributions of sustainability transitions treated the issue of space and place. These were only indirectly and implicitly addressed within both the dominant Multi-Level Perspective (MLP) and Technological Innovations Systems (TIS) heuristics. Within the MLP framework, for instance, much of the early research on the importance of space consisted in ascertaining the role of the local and global dialectic (Smith and Raven, 2012). Thus it was argued that local experimental projects (with new technologies, user preferences, infrastructures, regulations) occur in different localities; and when they become supported by global actors/networks they accumulate and transcend the local contexts (sometimes this process is interpreted in terms of local or urban transitions vis-à-vis national transitions; see for instance Geels (2011)). These references to the ‘global’ and ‘local’ processes are, however, considered highly abstract and are used in a spatially de-contextualised sense (Truffer and Coenen, 2012). While Hodson and Marvin (2009) emphasise that the importance of geography is often confined to ‘some sort of bounded experimental local context’ at niche level, Bridge et al. (2013) argue that concepts such as the local-global dialectic and landscapes are often mistaken for having a quite specific geographical meaning. A recent response to these criticisms, provided by Sengers and Raven (2015) highlights the complexity of networks in niche development, arguing that global networks become entangled with place-specific power relationships, institutions and infrastructure.

While initial contributions to the geographies of transitions explored the role of cities (Bulkeley et al., 2010; Hodson and Marvin, 2010), regions (Cooke, 2010; De Laurentis, 2013; Spåth and Rohracher, 2010, 2012) and power relations and social processes in regime and niche dynamics (Lawhon and Murphy, 2012; Murphy, 2015), a new research agenda for the geography of transitions has only been set since the contributions of scholars such as Coenen and Díaz López (2010); Markard and Truffer (2008); Truffer (2008); Truffer and Coenen (2012) and Raven et al. (2012). This agenda encompasses many fields and a number of methodological approaches (Hansen and Coenen, 2015) and according to Truffer et al. (2015) gravitates around three main building blocks: socio-spatial embedding, multi-scalarity and issues of power.

Responding to the call from Coenen et al. (2012: 976), that ‘transition research would do well to take a closer look at the global networks and local clusters of transition processes in conceptual, methodological and empirical terms’, both the socio-spatial embedding of
transitions processes and the issue of multi-scalarity have predominantly been investigated through exploring the complementarities between different innovation system approaches and contributions from economic geography.

Much innovation systems research uses three key scales, based on the territorial boundaries, of the global space (Bunnell and Coe, 2001; Cantwell, 1997; Carlsson, 2006; Carlsson and Stainkiewicz, 1991; Narula and Zanfei, 2005), the nation (Edquist, 1997, 2005; Freeman, 1987; Lundvall, 1992; Nelson, 1993), and the region (Asheim and Coenen, 2004; Asheim et al., 2003; Braczyk et al., 1998; Cooke, 1992). However, other emerging strands focus on the complex networks and interactions operating across and between these scales, providing a more fluid relational account of (scale in) innovation processes. It has been argued, therefore that accounts of innovation systems cannot focus any longer solely on these three discrete scales (Coe and Bunnell, 2003), but are, indeed, multi-scale (Hotz-Hart, 2000).

Recent literature on economic agglomeration and clustering processes, for example, offers important insights into the role of global-local networks and institutions that cut across and link different geographical scales (Bathelt et al., 2004; Maillat, 1998; Scott, 1998). Both Oinas (1999) and Bathelt et al. (2004) argue that the creation of new knowledge is best viewed as a result of a ‘combination’ of close and distant interactions. Bathelt et al. (2004) refer to these external linkages as the ‘global pipeline’, whereas ‘local buzz’ implies knowledge generated and shared locally. Whilst economic success often then has local roots, it also crucially depends on combining local and trans-local or global linkages (Asheim and Gertler, 2005; Bathelt and Glückler, 2011; Bathelt et al., 2004). This relational approach also has much in common with the heuristic framework of global production networks (GPN), in which, it is argued, the geographical complexity of the global economy is better understood via the concept of a network (Bunnell and Coe, 2001; Coe et al., 2008).

How the complementarities between different innovation system approaches and the contribution from economic geography are fruitful in understating the spatiality of transitions is better understood through looking at work that has built on the TIS tradition (Bergek et al., 2008; Carlsson and Stainkiewicz, 1991; Markard and Truffer, 2008). The work of several scholars (Binz and Truffer, 2011; Binz et al., 2014; Binz et al., 2012; Dewald and Fromhold-Eisebith, 2015; Dewald and Truffer, 2012; Wieczorek et al., 2015a; Wieczorek et al., 2015b) has contributed, both theoretically and empirically, to the understanding of the role of geography in TIS. In particular, this work highlighted four issues:

i) the coupling between the national and international levels of the innovation process. It argues that a multi-scalar TIS incorporates both localised and internationalised
structures as the international and multi-scalar networks of actors, localised clusters and institutions enable and coordinate the creation, utilisation and diffusion of a new technology. Transnational linkages, therefore, often complement local, regional and national capabilities enabling sustainability experiments;

ii) how national and international linkages not only depend on the technology in focus, but will vary according to the three layers of networks (science and technology systems, companies and markets and institutional contexts) within a TIS;

iii) TIS actors have to rely on critical resources that are often co-located in specific spatial contexts (at an early phase of a TIS’s development, for instance, important system functions such as market formation depend on locally bounded conditions, such as recurrent face-to-face interactions and the availability of locally specific institutional structures (Dewald and Truffer, 2012)); and

iv) the relative importance and relevance of different scales and actor constellations not only varies in a sector or technologic specific way but also shifts in time throughout the innovation process (for example with the ‘maturing’ innovation system - see for instance the case of photovoltaics in Germany in (Dewald and Fromhold-Eisebith, 2015)).

This review, although necessarily selective, has revealed that there are already meaningful contributions that acknowledge the importance of network relationships and the issue of spatial connectivity among actors and networks. As shown, some recent attempts to bring a stronger geographical perspective to sustainability transitions research build upon such contributions that draw together territorial and relational approaches in analysing economic flows (Bridge et al., 2013; Harrison, 2013; Jonas, 2012). Nevertheless, we contend, that recent contributions lack a full appreciation of the importance of the regional context for sustainability, and in particular low carbon RE, transitions. We argue that the regional context needs to be understood, more broadly, in terms of the wider institutional, economic and governance dimensions that may foster innovation and in terms of the natural (and built) environment and resource occurrence of energy (and RE in particular). Before seeking to outline a conceptual framework that addresses these deficiencies, we first turn our critical attention to the role of natural resources.

3. Natural resource endowments: understanding resources as both physical and discursive artefacts

This section starts by assessing the importance of natural resource endowments in RE innovation processes. It does so in several ways. Firstly it presents a brief account of how
scholars have emphasised the influence that natural resource endowments may exert on processes of RE innovation for a sustainability transition. Secondly, drawing from the literature on non-renewable resources, especially on oil and gas exploitation, and contributions from the resource economies literature it introduces the concept of materiality and the conceptualisation of renewable natural resources both as material and discursive artefacts. Thirdly, the section speculates about how the concept of materiality could add valuable insights for studying and understating processes of RE innovation.

Relatively few contributions have dealt explicitly with the importance of natural resource endowments (Hansen and Coenen, 2015) for sustainability transitions. Although it is argued that more could be done in taking local natural resource endowments into account in transition strategies (Trutnevyte et al., 2012), some empirical contributions point towards the positive influence that natural resources have played in RE innovation processes. Examples of these include, for instance, how the success of Brazil’s ethanol production depended, to some extent, on climate and soil conditions that allowed sugarcane production to thrive in the São Paulo and adjacent areas (which account for 85% of sugarcane cultivated in Brazil—see Goldemberg (2007); Solomon and Krishna (2011)). The influence of natural resources is further stressed by Carvalho et al. (2012) in their discussion of biodiesel and regional production of soya crops in Curtiba (Brazil) and also by Späh and Rohracher (2010; 2012) in their account of sustainability transition in the Murau region and the role played by woody biomass. Also, a recent study by Murphy and Smith (2013) analysed wind energy projects on the Scottish island of Lewis. This study explored the implications of land ownership and tenure and the importance of transmission infrastructure on untapped renewable resources in the Highlands and Islands of Scotland. Moreover, the growing appreciation of the scale of offshore wind (Jay, 2011), marine and tidal energy sources available to the UK (ABPmer, 2008), suggests that they are rapidly becoming recognised as valuable assets. In particular ABPmer (2008) and Jay (2011) stress that the availability of relatively shallow windy waters, wave and tidal currents with centres of high demand close to the coast might facilitate the appropriability of these resources.

The starting point of this paper is that, contrary to the generalisation that renewable resources (with the exception of large hydro and geothermal) have the inherent characteristic of being plentiful and widely dispersed around the globe (Sims et al., 2007), the spatial distribution of RE resources and their potential availability varies over time and between locations. This characteristic of RE resources sits in contrast with the physical flows of mineral, gas and oil extraction that have a strong regional dimension, as the localised and variable quality of the latter resources means that some regions have greater natural endowments of them than others (the phenomenon that underpins Ricardo’s theory of
differential rent) (Bridge, 2009). Nevertheless, RE resources do present regional variations, and these variations are not only caused by the resource characteristics (wind speed, solar irradiation and soil quality, to name a few) but also by geographical (land use and land cover), techno-economic (scale, labour cost), institutional (policy regime, legislation) factors (de Vries et al., 2007) and infrastructure endowments. Natural flows of renewable resources are thought to be immense in comparison with global energy use (Johansson et al., 2004). Yet, natural renewable resources are widely and unevenly dispersed, as they are to an important degree dependent on specific physical, cultural, economic and technological characteristics and appraisal (Zimmerer, 2013).

Zimmerman’s dynamic concept of natural resources that vary over time and space is useful here. He argues that ‘resources are not, they become: they are not static but expand and contract in response to human wants and human action’ (Zimmermann, 1951: 15). Resource and environmental geographers have predominantly conceptualised nature in physical terms, traditionally focusing on improving the flow of resources ‘from’ nature ‘to’ society through the design of institutional and territorial frameworks for procuring and managing environmental goods and services (Bakker and Bridge, 2006; Bridge, 2009). Bakker and Bridge (2006) suggest that what counts as a resource depends on the interaction between its physical quality and condition (e.g. the variable grade/quality of mineral resources, for example) and social institutions. Referencing the material, they contend, is to acknowledge that ‘things other than humans make a difference in the way social relations unfold’ (Bakker and Bridge, 2006: 18). In this sense, they continue ‘materiality matters because of the way its heterogeneity differentially enables, constrains and/or disrupts the social practices through which resource regulation is achieved’ (Bakker and Bridge, 2006: 21). In other words, materiality provides a way of acknowledging resources in dialectical terms as a combination of physical and discursive practices - a socio-natural phenomenon that takes shape through interaction between the material/physical world and individual activities, institutional agendas and industrial forms of organisation.

Bridge (2008) has drawn increased attention to the materiality of production networks. His work follows from a criticism that much of the production network literature pays little attention to the institutional and geographical environments in which networks operate. Using the example of the oil industry, Bridge highlights the influence that materiality exerts on industrial organisations within it. He argues that the production chain of extractive industries is territorially embedded at different points. The industries’ materiality emphasises the ways in which the dependence on natural production, the location relative to markets and the existing infrastructure limit the spatial flexibility of the network.
Kaup (2008: 1736) arrives at a similar conclusion, indicating that the ‘material difficulties of natural gas extraction and transport have shaped the structure of Bolivia’s natural gas industry’. The extraction and transport of natural gas requires much fixed capital and technological innovation in extraction and separation processes, pipeline construction and conversion. The requirement of capital, Kaup (2008: 1737) argues, ‘has shaped the relationships between transnational extraction firms and the people and places in which natural gas is extracted’. In this sense, the issue of materiality highlights that natural resources are both naturally endowed (the influence that they exert vis-à-vis the physical properties - e.g. land requirements and energy density - and the geographical recurrence) and socially induced (e.g. recognising how a diversity of actors can construct and manipulate nature).

Agreeing that natural renewable resources are to an important degree dependent on specific physical, cultural, economic and technological characteristics and appraisal, we could argue that although resource potentials and resource assessment are often presented as ‘objective’, most of them are strongly influenced by assumptions on average values and trends that are often influenced by the purposes of the assessment and the actors involved. While resource assessment often requires a set of context related additional assumptions and refinements that include site-specific judgments and regional estimates, that are not often widely available (de Vries et al. (2007), the argument here is that resources are far more than economic, but rather have irreducibly social and cultural roots (Bakker and Bridge, 2006). Drawing parallels with the literature on non-renewables, it can be argued that resource potential, and its assessment, is not only the fruit of geological and natural processes but also of a continual socio-economic appraisal about the utility and value of the resource (Bridge, 2009). Bridge (2004: 416) argues that changes in societal demands, in market prices and/ or cost of extraction, exploration activity and/ or the introduction of new technologies can lead to the identification of new reserves in places where, to all practical purposes, none previously existed (and, indeed, in some cases estimates have also been subsequently revised downwards).

This discussion emphasises that natural RE resources, their geographical recurrence and the infrastructure requirements for the delivery of RE energy are important features in RE transitions: geographical recurrence and knowledge flows about natural resources, together with the natural (and built) environment as a source of competitive advantage (and constraints) are likely to be territorially embedded at different points in the value chains. What constitutes renewable natural resources will be contained within a particular physical territory but also be socially and politically constructed as such within and between various networks of actors at different scales. Our intention here is not to over-privilege material
explanations and to revive the ghost of physical determinism (see for instance the challenges of natural resource-based development4). Nevertheless, we think that the issue of materiality, and how resources can be both materially manipulated and socially constructed, is valuable in understanding innovation processes and spatial consideration in RE systems. We turn our attention next to highlight why materiality matters in researching RE innovation.

4. Understanding the role of materiality in renewable energy innovation

This section provides an account of the importance of, and the reasons why, materiality should play a role in researching RE innovations. It does so by presenting a set of arguments that acknowledge the multiple processes through which ‘natural resources’ are generated as both material artefact and discursive construct. These include: i) natural resources as predominantly associated with the physicality of resource occurrence; ii) natural resources as discursive constructions that actors use to promote their interests; iii) natural resources as embedding specific physical characteristics and infrastructure requirements.

4.1 Natural resources as predominantly associated with the physicality of resource occurrence: targets, resource assessments and land-use conflicts in Renewable Energy

The renewed interest in the exploitation of RE sources to fulfil a number of objectives (that span from security of energy supply, resource diversification to avoiding the emissions of greenhouse gases and more broadly the issue of climate change) has induced unprecedented developments in RE and RE policies. This has given new impetus to the assessment of potential RE resource availability. Several estimates have been produced of the worldwide potential for RE options for each renewable resource, together with associated scenarios that use a combination of data observations and mathematical models (de Vries et al., 2007). The exercise of producing such estimates for each renewable resource, has resulted in the publication of associated scenarios and roadmaps at different spatial levels. These roadmaps and scenarios have become important tools for future planning of energy supply developments and helped in identifying targets for RE production at the European, national and regional scales.

Legally binding EU targets have been issued for the share of electricity production from renewable sources and Member states have also produced strategies and measures to
meet their binding 2020 targets. However, it has been argued that target setting has been
influenced by a sense of urgency to trigger investment in new capacity (Haas et al., 2004;
Szarka, 2007). This urgency led most of the assessments - and the (mathematical)
economic models underlying energy policy designs - to rely on the implicit assumption of an
homogeneous space differentiated solely by energy gradients (solar irradiation, wind speed,
tidal currents, etc.) (Nadaï and van der Horst, 2010a).

The problems associated with this approach are evident once we consider that, compared to
conventional fossil fuel-based energy systems, RE sources are more space-intensive (given
their much lower power density (Smil, 2010)) and their efficiency of energy production is
highly geographically dependent (Dijkman and Benders, 2010; Seager, 2009).

The pursuit of the low carbon transition agenda holds unusually profound implications for the
provision of ecosystem services (NERC, 2014). Undoubtedly, the potential implications of
RE for ecosystem services are often site-specific, depending on the size and nature of the
projects. A goal of governments, at different spatial levels, is to regulate the ecological
relations between economic and competing social demands that address potential conflicts
and trade-offs between RE development and the provision of ecosystem services. Thus, for
example, RE innovation and the production of electricity from renewable technologies
involve the use of greater areas of land, per unit of electricity generated, than the more
traditional energy forms. Further land requirement is necessary for the construction and
maintenance of access roads and buffer zones. Additionally, land is also needed for
extensive transmission infrastructure (e.g. rights-of-way and high voltage power lines) in
order to export electricity from the sometimes distant points of production, to major urban
and industrial areas (Smil, 2010).

Land use has, therefore, become ‘the most important environmental consideration in the
development of these resources’ (Pasqualetti, (1990), cited in Walker (1995)). The
stimulation of RE technologies and RE development, together with the management of the
multiple uses of land and land availability, have prompted a multidimensional debate that
encompasses tensions between economic, social and environmental concerns, at the
different scales - from local to global - at which these operate (see for instance Walker
(1995)). The low energy output per unit area of wind power and the requirements of exposed
onshore sites (MacKay, 2009) have created greater potential for extensive disruption of
existing landscapes and the values attached to them. This has spurred extensive research
that analyses the evolving relationship between landscape, energy and policy (Nadaï and
van der Horst, 2010a; Nadaï and van der Horst, 2010b); see also Bridge et al. (2013)).
Competing interests for land resources and the multiple uses of land are often the result of
negotiations between many variables that include, among others, planning systems and institutional infrastructure, socio-cultural characteristics as well as environmental priorities (Keenleyside et al., 2009).

For the purpose of this paper, therefore, we argue that the account above highlights how materiality is essential and useful in understanding RE innovation and how RE resource potential and capacity interact with the contextual conditions in which they are developed and deployed. Materiality matters here as it influences the socio-economic appraisal of resource assessment and their potential via the iteration between spatial resource assessment potential and land use protection.

4.2 Natural resources as discursive constructions that actors use to promote their interests: narratives and visions of renewable energy

Because natural resources are both physical and social constructs, resource appraisal and assessment also imply that more careful consideration needs to be given to which resources do or do not become incorporated into the construction of spatial maps, and the extent to which these spatial representations are accepted or resisted by different actors (cfr. Power and Cowell, 2012). Research on the opposition to RE development argues that, in most cases, the potential for conflict is not strictly technological in nature but lies in the highly contextualised way in which (in)compatibility and (un)suitability (of energy and landscape) are perceived, narrated delineated or negotiated by different stakeholders and the public’ (Nadaï and van der Horst, 2010b: 182).

If we understand natural resources as a discursive construction that actors use to promote their interests, then, it could be partly argued that actors, at different spatial scales, can promote or hinder resources and their abundance with different storylines (cfr. Hajer, 1995). These might narrate the reality to simplify and influence strategic policy priorities (De Laurentis et al., 2016; Teschner and Paavola, 2013).

Earlier in the paper, we have delineated how climate change and energy security imperatives have spurred a renewed interest in RE deployment and induced a specific configuration of interests (Nadaï and van der Horst, 2010a). Such attention towards renewable capacity increases has raised questions about the pace and scale of RE development. This has highlighted two important issues: firstly, the significance of mobilising discourses to attain policy purposes, rally actors and aggregate resources (Szarka, 2007); secondly, it has shifted attention to establishing what discourses related to RE gain hegemonic status and which are marginalised (cfr. Lupp et al., 2014). Szarka (2007), for
example, offers an interesting account of the development of RE in France, highlighting how the dominance of the nuclear sector has diluted the power of discourses that have emerged in favour of RE, reducing the room for manoeuvre and effectiveness of renewables policy.

Similarly, abundant natural resources may lead to ‘imaginative geographies’ and reproduce ideas about nation-building, national identity and citizenship and territory, as argued by Bouzarovski and Bassin (2011). Energy sources are often woven into discourses and debates about identity, image and significance of nation states in the global arena, and a nation’s or region’s visions of its own future development (Perreault and Valdivia, 2010). Such incorporation of identity narratives in the articulation of RE and technologies (development) can drive the exploitation of natural resources associated with particular energy development paths (cfr. Essletzbichler (2012)). Späth and Rohracher (2010), for instance, highlighted the role of visions for biomass in RE development in Murau (Austria) and the way in which they attracted resources and motivated actors to change.

In this sense, the focus on materiality brings attention to the actors and the way they create particular vision(s) of identity, at different spatial levels, with the aid of, and in relation to, natural resource endowments. Materiality offers an opportunity to broaden the understanding of RE development to fulfil particular visions or trajectories of particular scenarios, stressing the conflicts, powers, interests and priorities of the actors involved.

4.3 Natural resources as embedding specific physical characteristics and infrastructure requirements: the natural environment and the built infrastructure

Both the specific physical characteristics of the natural resources and the requirement of a robust infrastructure to deliver energy (due to, again, the particular characteristics of the natural renewable resources) can exert significant influence over how energy innovation networks generate and capture value. Thus RE technologies might emerge in one or more places where natural conditions and specific physical characteristics favour testing of and learning about technical specificities - such as for instance remote and difficult environments for the testing of sensor technologies for offshore or marine technologies. Likewise, technologies might emerge in places where further enhancements are added to particular technologies to address locally specific problems (e.g. vis-à-vis load transmission capacity, balance management and storage in areas of excessive solar irradiation). Such activities could provide the seedbed for further targeted local, regional and national policy interventions.
Moreover, RE activities can emerge in places where the physical characteristics of the environment surrounding the natural resource make it more practical to harness the renewable source (e.g. lagoons, sheltered coastline, well-developed grid system and port infrastructure). To clarify with an example, areas that display a well-developed grid system and port infrastructure - deemed to be important characteristics for the commercial success of offshore renewables - and with favourable local weather conditions and local geography (e.g. accessible onshore areas suitable for assembly and maintenance), could strongly influence the exploitation of these resources (Murphy et al., 2011).

Nevertheless, infrastructure networks or their absence could also represent barriers for technological innovation and deployment. Thus, global, national and regional power and infrastructure networks become intimately connected through the materially embedded transmission grids within specific territories (Hiteva and Maltby, 2014) and interconnections, if any, between them. The built infrastructure, including the built environment, therefore, becomes an important mediating factor between the physical resource endowments and institutional/ governance structures, creating inertia and path dependencies (such as in the case of the national grid infrastructure in the UK that has hampered and delayed RE developments, see for instance Wood and Dow (2011)), constrain the feasible innovation trajectories. Moreover, areas in which the infrastructure is already present become more attractive to global investments. This highlights the importance and the challenges of strategic investments in the transmission and distribution electricity networks as the number and volume of distributed generation connections increases.

In this respect, materiality stresses how the specific physical characteristics of the natural resources and the requirement of a robust infrastructure to deliver energy influence energy innovation networks and their ability to generate and capture value in RE development.

4.4 Why materiality matters in renewable energy innovation: a summary

The account presented above has argued that foregrounding the issue of materiality in RE research is valuable. It provided a set of arguments about how we can enrich and diversify the homogenizing economic thinking, which has prevailed in the analysis and construction of RE applications and development. In summary, we argue that:

Materiality and physical characteristics of renewable resources influence the socio-economic appraisal of resource assessment and their potential via the iteration between spatial resource assessment potential and land use protection. Materiality can, therefore, become part of the way in which we seek to understand how resource potential and capacity interact with the contextual conditions in which they are developed and deployed.
An appreciation of materiality- and the discursive constructions that actors use to promote their interests influencing narratives and visions- is important in understanding processes of RE innovation. In this respect, it offers an opportunity to broaden the understanding of RE developments and the way they fulfil the visions and trajectories of particular scenarios but also to investigate the conflicts, powers and priorities of socio-technical change;

Natural resources can present specific characteristics in certain territorial contexts that can provide greater market potential for exploitation. Materiality also draws attention to the importance of the pre-existing built-infrastructure in maximising RE potential.

To some extent, the account presented also focuses attention on the existing local economic and technological structures, knowledge, competences and capabilities that can be mobilized through the purposive actions of agents, resulting in the emergence of new innovation paths (Cooke, 2012; Dawley et al., 2015) and also Dewald and Truffer (2012) and Dewald and Fromhold-Eisebith (2015)). What follows seeks to highlight how RE technologies interact with the contextual condition in which they are developed and deployed, illustrating how materiality might influence institutions, governance and firms’ decision making about RE investments at the regional level. The regional lens is here used to unpack the role that natural resources play in innovation as it represents the level at which both scale and materiality coalesce. Within the region a broad spectrum of RE systems might co-exist (e.g. wind, solar, bioenergy, marine geothermal, etc.). These are, as we argue, in turn, influenced by the opportunities and constraints offered by the different regional institutional, economic and governance contexts and materialities.

5. Towards the development of a conceptual framework

So far, in the paper, we have argued for recognising how materiality can influence RE innovation. Now we elaborate this in terms of how materiality might exercise this influence at the regional level. We then introduce a conceptual framework that clearly reconceptualises the materiality dimension in RE innovation research.

5.1 How materiality might influence institutions, governance and decision making at regional (and other levels)

Firstly, we have argued for recognising how materiality can influence the socio-economic appraisal of resources and their potential via iterations between spatial resource assessments and land use protection. As stressed earlier, targets at different scales have been set for increasing the level of electricity production from renewable sources. In some countries, although the centre continues to retain considerable powers over energy policy,
there has also been an increasing role and influence of sub-national (regional) actors in promoting renewables. Resource assessment, in this sense, has also become a product of policy while informing it. Writing about the emergence of regional governance in RE in the English regions in the early 2000s, Smith (2007) argues that a key task at the regional governance level was to persuade others that RE was vital for the development of their region. This process of persuasion started with the appraisal of renewable resources at regional level, resulting in embedding RE targets into overarching economic strategies. RE resources and the potential renewable capacity available at regional level were then fed back into the UK final RE strategy to ensure the twofold aim of meeting the targets - building from a strong evidence base - and making sure that sufficient locations for RE deployment would emerge from this process (Arup, 2009).

Moreover, Cowell et al. (2015) argue that RE governance in the UK is not directed by a dominant strategic line cascading top-down from EU commitments. The devolved governments of Scotland, Wales and Northern Ireland have each produced an energy strategy, including setting their own renewable energy targets, together with their own regional visions and aspirations for RE development. These, Cowell et al. claim, reflect mainly ‘domestic’ processes such as political agenda setting, along with assessment of the RE resources available within each territory and projects in the pipeline. The process of target setting was therefore not influenced by Westminster seeking to steer the devolved organisation into delivering any specific share of the national commitments. Other countries such as Italy, on the contrary, adopted a principle of ‘burden sharing’, through which regions, starting from their regional technical and economic potential for each RE source, are asked to contribute towards the national target via a binding regional target.

Furthermore, the sense of urgency over RE capacity increases has, in some European countries, encouraged the support of market-ready technologies that could deliver the cheapest renewable electricity by promoting RE investment in the best available sites. Processes of resource assessment, target setting and spatial planning like those described, provide interesting insights into the regional scope, and environmental implications, of different RE technologies and low carbon transition pathways. Agreeing with Wolsink (2007), the success of national policies for the implementation of RE, ultimately depends on the number of successful projects in which renewable resources are applied at regional and local levels.

The role of RE planning policies, therefore, has emerged as an important policy issue in influencing RE development and in understanding the challenges that renewable technologies present for the management of land use and the possible responses ((Walker, 1995) (Toke et al., 2008).
These challenges are understood through analysing the processes of weighing resource potential and different environmental values against RE targets, often articulated through deliberation between national, regional and local stakeholders (Cowell et al., 2015; Cuocolo, 2011). This is exemplified through the construction and operationalisation of the choice of variables to be mapped spatially (cfr. Cowell (2010); and Ellis et al. (2013)). While planning institutions, at both national and regional levels, are often required to mobilise a dominant strategic line around the delivery of specific objectives and/ or guidance, it is the local authority or the municipality that often engages with local stakeholders and can design locally tailored implementation strategies in accordance with local specificities and priorities.

For instance, McKenzie-Hedger (1995) provides a detailed analysis and critique of how the development of wind energy in the UK in the early 1990s was driven more by energy policy than by land-use policy traditions. She argues that wind power was developed within the culture of energy policy, with its supply bias; consequently, the local environmental impacts of wind had been neglected in the drive for rapid expansion. Cowell (2007), using the example of Wales, points to the use of spatial planning policies and institutions to mobilise a dominant strategic line around the delivery of specific targets and objectives. These promoted the preferential siting of large-scale renewable schemes, led by a technocratic approach based on resource potential (cfr. Stevenson, 2009). Spatial planning therefore reflects the capacities and willingness of governments, at different scales, to render land available for RE development and manage social response (Cowell et al., 2015).

Moreover, regional and national governments are able to negotiate stringent requirements for consenting RE projects, requesting for instance that a certain percentage of value from the development is derived from domestic content, to boost the regional/ national economies. Offshore wind in the UK provides an example, in which planning consent for future offshore wind farms is set to aim for 50% of value from domestic content (Dawley et al. (2015). Regional actors can also play an important role in facilitating the dialogue between different actors at different scales. This is relevant, for instance, in the development of marine and offshore energy in the UK. The collaboration between industry, government and stakeholders at nation and regional levels with the Crown Estate, responsible for leasing areas of the seabed and managing the associated seabed rights, is increasingly considered important in bringing new development opportunities to the market in the offshore and marine energy sector in the UK (Kern et al., 2014).

Secondly, we have considered the importance of materiality and the discursive construction that actors use to promote their interests, and how these might influence narratives and visions around RE and promote particular energy development paths. In many cases, regions, although they may lack control over economic framework conditions (e.g. subsidies
and feed in tariffs), can mobilise a coherent shared vision(s) for the exploitation of their indigenous renewable resources. This enables them to be translated into more concrete agendas that reflect the specific requirements and opportunities of particular regional contexts. The recent Scottish independence debate offers an example of how such imagery of natural resources, identity and RE paths can play out ((cfr. Dawley et al. (2015) and Toke et al. (2013)). In particular, Scottish independence was presented as an opportunity to take control over energy policy and ultimately to increase the opportunity of pursuing RE priorities due to the abundance of natural resources5. Identity narratives linked to regional resource abundance have also played an important role in encouraging offshore wind path creation in North East England (Dawley et al. (2015)).

Driven by such discursive constructions, regional institutional systems can form temporary windows of opportunity for technological innovation (cfr. Dewald and Fromhold-Eisebith, 2015), as they set up ambitious deployment policies and support state-led projects aimed at harnessing natural resources. Nevertheless, regional ‘visions’ could also oppose large scale RE development aimed at harnessing natural resources, in the pursuit of maintaining a balance between energy production and landscape values (cfr. Bridge et al. (2013)). Nadaï and van der Horst (2010a) argue, for instance, that looking at energy through the lens of landscape, can provide a situated point of view, which helps grasp how technologies and energies are embedded into territories and local communities. In this respect, landscape can be understood as a complex and multi-faceted cultural and political process (Nadaï and Labussière, 2009). It draws attention to the material as well as the relations and social networks that play a role in providing meaning to a specific area (e.g. the cultural, rural and scenic landscape). On the one hand, narratives and visions around RE can mediate the contextually-embedded qualities of the landscape alongside other considerations such as resource abundance and resource availability (Cowell, 2010). On the other hand, the level at which real decisions are taken about investments and the siting of RE power schemes becomes crucial (Wolsink, 2007).

Thirdly, we have suggested that the materiality of natural resources draws attention to the importance of the pre-existing built infrastructure and specific characteristics of the resource and how they might influence innovation processes in RE. RE innovation is influenced by contextual factors, including the built environment, the energy infrastructure and current industry structure. As RE capacity increases, the current infrastructure (e.g. grid connections) might represent a constraint or an opportunity for future development. Some countries have already invested for instance in grid reinforcement, such as Germany (Szarka, 2007), and at the regional level, where the problem of grid saturation (and unavailability of new grid connection) is felt, regional governments might have both the political legitimacy
and the resources to participate actively in infrastructure renewal (e.g. channelling European funding for infrastructure development and update). Similarly, Dewald and Truffer (2012), in their account of regional growth differentials in the German Photovoltaics market, point out the role that the built environment has played, showing how RE innovation has flourished more successfully in rural and suburban areas than in urban areas.

Emerging industries, such as that of RE, it is argued (Klitkou and Coenen, 2013) often arise out of a process of recombination, renewal and knowledge spillovers facilitated by a combination of complementary industries within a region. The existing local economic and technological structures, knowledge and competences can be mobilized by regional actors to renew the economic structure and promote new development paths (cfr. Dawley, et al., 2015; Cooke (2012), Asheim et al. (2011); Boschma and Iammarino (2009); Frenken et al. (2007).

Hence, the materiality of the resource will shape the path along which not only niches and experiments thrive but also the entire trajectory of the innovation journey (as for example in the case of more mature renewable technologies, such as onshore and offshore wind (Power and Cowell, 2012)). Furthermore, such materiality might influence, to a certain degree, decisions about investment locations, representation of new development opportunities (e.g. incentivising local and regional communities to make more sites available) and the development of ad-hoc industrial policy.

Table 1 provides a summary of the arguments presented here, suggesting how the materiality dimension might influence networks and innovation processes that in turn influence the institutional, economic and governance dimensions at regional level.

Nevertheless, the arguments presented have also highlighted the importance of the national and international institutional frameworks and their interaction with regional and local institutions and organisational networks. Economic geographers (see for instance Gertler (2010), stress the importance of the national institutional framework and argue that this interacts with localized networks and local/ regional institutions that help shape organizational practices and learning processes. Agreeing with Martin (1994), regions are places in which different institutions- local, regional, national and international- meet. The issue of scale is therefore important here. In other words, as noted, regional governance, regional policy and regional-specific institutions result from or are influenced by processes that take place at and across various scales, becoming entwined, constructed and networked to other places and people beyond any given jurisdictional territory (Goodwin, 2013).
Table 2 summarises the institutional conditions that are relevant for understanding processes of RE innovation. In particular, it draws attention to the institutional conditions that affect the behaviour of the actors involved within RE systems and draws attention to the scale at which this happens. The institutional conditions and the incentives they create at any particular scale will interact, influence and are influenced by the institutional architecture at other geographical scales (cfr. Gertler (2010) and Rodríguez-Pose (2013)). Each spatial scale, as detailed in the table, is distinctively marked by particular institutional characteristics and points to the varying capacities of regional and local economies, in terms of political legitimacy and resources.
Table 1. Understanding the importance of materiality in renewable energy innovation dynamics at regional level

<table>
<thead>
<tr>
<th>Natural resource occurrence</th>
<th>how materiality might influence networks</th>
<th>how materiality might influence regional preconditions (such as institutions, governance and firms decision making)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural resources as predominantly associated with the physicality of resource occurrence</td>
<td>Delivery of national/EU/ and regional targets; Iteration between spatial resource assessment potential and national targets; The processes of resource assessment stimulates deliberation between regional stakeholders about weighing of different environmental values against RE targets (these are done at different scale); International players seek local ties to negotiate planning environment (e.g. global companies often have financial ties with regional renewable companies that hold research or land-use permits)</td>
<td>The regional level often has responsibilities over regional economic development and planning; Construction and operationalisation of mapping methodologies e.g. spatial planning; Negotiation between energy policy (targets) vs. land use policy traditions and values - Limit to expansion and deployment - Pressures for &amp; regional responses for transformation and RE development; Strategies that draw upon siting criteria to create new representation of development opportunities: - incentivise local communities to make more sites available - Developers dash to exploit most commercially attractive locations - Attraction of inward investments; Regional renewable companies might hold research or land-use permits and have the know-how to negotiate/understand local planning issues</td>
</tr>
</tbody>
</table>

| Natural resource abundance | The exploitation of natural resources for energy are woven into discourses and debates about a nation/region’s identity, its image, international relations, a nation’s path of future development and visions and its significance on the global arena; Reproduces ideas about nation/ region building/ national/regional identity and citizenship; Nature is something governed, consumed and marketed locally and globally | Which characteristics of the resource become incorporated into mapping and which get excluded and the extent to which (these spatial representation) are accepted or resisted by different actors; Locations as sources of inward investment (‘open for business’); simplification of legal and regulatory frameworks to support ambitious deployment policies; Coherent narratives provide legitimisation on a particular process of regional development and RE and are used as a conduit and a way of communicating the articulation of particular RE development paths; Regional actors and governance systems channel finance and support of RE technology/ promotion of R&D solutions and technological development |

| Natural resource characteristics | Technologies emerge in places, in which natural conditions and specific physical characteristics favour testing and learning of technical specificities and/or where further development or new qualities are added to particular technologies; Areas in which certain characteristics of the resources provide great market potential and best climatic conditions- these areas attract the attention of large foreign utilities that aim to exploit the resource (e.g. offshore wind in UK; geothermal in Tuscany, Italy) | Researchers and technology developers choose sites for testing and experimental activities according to the availability of natural resources; this is particularly relevant to emerging technologies; Potential sites are promoted for demonstration projects and experimental platforms; Existing local economic and technological structures, knowledges and competences are mobilized through the purposive actions of agents resulting in the local emergence of new paths; Creation of umbrella organisations to provide support and coordination among actors (universities and firms links), support network formation and skills/ competencies development; Universities provide laboratories for testing; Testing and learning area for proto-market development; Regional governments provide funding for local infrastructure development (e.g. production, distribution and storage) |
Table 2. Institutional framework and scale for understanding the role of materiality in RE innovation processes

<table>
<thead>
<tr>
<th>Institutional conditions</th>
<th>Local</th>
<th>Regional</th>
<th>National</th>
<th>International</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Financial incentives:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subsidy</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td><strong>Allocation of financial resources:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- R&amp;D</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>- European Structural Funds</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td><strong>Standards</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Building regulations/ building provision</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quality standards</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Legislative</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Target setting</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>RE targets</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Environmental policy targets</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td><strong>Spatial Planning</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planning and land use law</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Land use right assignments/ land ownership</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Planning for RE expansion</td>
<td>X</td>
<td>strategic</td>
<td>strategic</td>
<td></td>
</tr>
<tr>
<td><strong>Non-economic incentives</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>capacity building and demonstration project</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>investment in infrastructure</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Culture</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>participative and reflexive governance in planning</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Identity</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>
It follows, therefore, that RE innovation will be determined through the interplay between inherited (but also co-evolving) international, national, regional and local institutional structures. Nevertheless, agreeing with Gertler (2010), regionally and locally distinctive institutional architectures can and will shape innovation processes, leading to differentiated social and economic outcomes. Dewald and Farmhold-Eisebith (2015), in their analysis of PV technology development in Germany, point to a similar conclusion when they interpret the distinct qualities of innovation system scales in terms of ‘institutional spaces’.

5.2 A conceptual framework that reconceptualises materiality in renewable innovation systems

The contributions spanning the economic geography field, coupled with the recent developments in the geography of transition, have highlighted an important aspect of researching RE innovation. Following the view that scale is a fluid, relative and socially constructed concept (Bunnell and Coe, 2001), we can argue that RE innovations are intertwined across a range of scales and spheres of governance that call for a better understanding of the role of actors, networks and institutions as they operate simultaneously across multiple scales.

However, the paper has highlighted that such a fluid relational account of scale in innovation runs the risk of undermining the importance of the spatial context and the role that natural resource endowment can exert and their impact on network relationships. The physical properties of a resource (whether it is ubiquitous or localised, whether it requires the mobilisation of significant amounts of energy/capital, land use and supporting infrastructures and so on) influence the political-economic relations within which the resource becomes embedded (Bakker and Bridge (2006)). Such material differences become significant because they might enable or constrain the social, political and economic relations necessary for resource production and innovation. Researching RE innovation, therefore, requires a more focussed attention on the role that geographical location and the materiality of renewable resources play.

What follows outlines a first attempt at a framework that reconceptualises the materiality dimensions in RE innovation systems. This framework stems directly from the arguments presented above. It draws attention to the influence that materiality exerts on RE innovation. This influence can be explained in terms of i) the physical and natural occurrence of resources and their energy density implications; ii) the opportunities and constraints that a robust built infrastructure provides for the delivery of RE from its point of capture and iii) the
ways in which actors construct visions and strategies around particular RE innovation paths and abundance discourses.

The framework acknowledges the importance of the institutional context and the institutional embeddedness of technological development processes and how this can explain different innovation paths, as some recent contributions from the geography of transitions literature point out. Nevertheless, foregrounding the issue of materiality in RE innovation allows for greater emphasis to be placed on which types of institutions – formal and informal7 - matter for RE innovation. Undeniably, RE innovation implies a relatively strong influence of policy regulation and economic support. Nevertheless, institutions not only shape but are also shaped by place-specific informal institutional structures, such as trust, culture, history and identity. As argued above, these are key elements that help to understand the influence that materiality exerts in RE innovation processes (e.g. in the case of narratives and visions, in influencing the meanings of landscape in land-use conflicts and mobilising actors and resources).

Two issues also need emphasising here. Firstly, as argued, emerging industries, such as that of RE, arise out of a process of recombinantional, renewal and knowledge spillovers facilitated by a combination of complementary industries within a region. Secondly, although institutions (both formal and informal) ‘influence choices and constrain decisions regarding practices, they do not wholly determine them’ (Gertler, 2004: 7-8). In other words, there is a major role for an agency of firms and organisations. Stenzel and Frenzel (2008) provide an example of this in their account of how firms (in particular the national electricity utilities), in Germany, Spain and UK, have coordinated the development of their technological capabilities and their political activities to shape and influence the regulatory environment relating to RE.

The proposed framework, borrowing from recent research on the regional innovation system, stresses the importance of evaluating the organisational presence, that is the organisational thickness (or thinness) of a region (Tripl et al., 2015) . This refers to the existence (or absence) of a critical mass of firms, universities, research bodies, support organisations, associations and other organisations and their economic and social interactions. Such a critical mass of organisations, together with research and financial capabilities, at regional level, might indeed be needed to both create and enact institutions (see for instance Zukauskaite et al. (2016)) that promote and/or hamper processes of RE innovation. The framework also takes account of the growing awareness of the effects of non-local/ non-regional as well as local and regional factors.
The arguments presented suggest that institutions and material differences are highly context specific: institutions and materiality both interact and are influenced by complex place-base interactions, which occur at both local and regional levels. The conceptual map provided in Fig 1 and outlined in low-resolution tabular form in Table 3 (which, with cells completed, could be used to provide a synthetic snapshot of a particular region) stresses the framework’s distinctive features:

1. attention to the existing institutional variety at different spatial scales (variety in terms of formal institutions, as well as type 1 informal institutions that influence cooperative and collaborative behaviours between the actors in the systems and type 2 informal institutions that influence and provide meanings to particular areas);
2. attention to the existing organisational capacity and effectiveness, to help assess the extent to which there is a critical mass of actors in RE but also in related sectors, as well as the availability of research, governance and financial capabilities that promote and/or hamper processes of RE innovation at regional level and how these relate to external networks;
3. a focus on the interdependence of and interaction between institutional and organisational structures and materiality.

In this sense, the arguments presented here take proper account of how:

i) physical and material differences, different formal and informal institutions, different organisation endowments and their corresponding efficiencies and interactions are unevenly distributed over territories,

ii) very similar institutional settings and material opportunities and constraints can work in different ways in different territories and

iii) territorial differences and material explanations can account for some of the observed differences in RE innovation and deployment, both over space and time cfr. Farole et al. (2011).
This framework, while attempting to abstract from the complexity of researching RE innovation at multiple scale, fosters attention on the various relations that materiality triggers in respect to innovation processes and the different roles that materiality can play in different regional and industrial contexts. This emphasis on the material characteristics of resources and how the technical potentials of different RE technologies interact with the contextual condition in which they are developed and deployed represents, it is hoped, a useful addition to the literature that will help explain uneven regional processes of RE innovation.
<table>
<thead>
<tr>
<th>Region 1, region 2, etc.</th>
<th>Presence and perceived effectiveness</th>
<th>Material opportunities and difficulties</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>low</td>
<td>high</td>
</tr>
<tr>
<td>Type of institutions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Formal institutions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E.g. subsidies and incentives, targets</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Informal institutions type 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E.g. cooperation and innovation culture (including how this might influence participatory planning approaches)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Informal institutions type 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E.g. culture, history and identity (how this influences and provides meanings to particular areas)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Organisational density</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Entrepreneurial capacity/ industrial diversity/ combination of small/ large firms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Support Organisations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Governance and research capabilities</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Financial resources</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(e.g. attract capital)</td>
<td></td>
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</tbody>
</table>
Empirical testing and further iterative refinement of the concepts proposed is, of course, required and the paper opens many avenues for further research. The two substantive sections presented above have started to articulate and identify a possible research agenda that could improve our understanding of the importance of context and a more nuanced treatment of space in RE innovation research. In order to contribute to a nascent field of study, this research points towards the need for new and more synergistic collaborations that bring together scholars with different disciplinary backgrounds (from geography, transitions and innovation studies) to promote interdisciplinary debate on how we conceptualise space.

As argued, whilst addressing the issue of scale and multi-scalar processes, the framework is firmly situated at the regional level, implying that the region is a key meeting place for systems of culture, politics, economy and materiality that coalesce from different spatial and territorial scales. In this respect, we argue that there is a need to re-engage with the concept of the region as a vehicle for framing how material, political and economic processes occur and meet at this scale. Regions can be looked at from a variety of perspectives, some of which foreground the political, economic and technological aspects, while others concentrate on issues of culture and identity (Goodwin, 2013; Harrison, 2013). It is perhaps on this latter perspective that further research should focus its attention. As seen, analyses of regional innovation systems have been very useful in identifying distinct regional and local institutional environments conducive to innovation. Similarly, the role that institutions play in the promotion (or hindrance) of innovation processes has increasingly attracted the attention of economic geographers and transitions scholars. While it is useful to look at the synergies with past and future research in these areas, more should be done to understand how institutions are shaped by place-specific informal institutional structures, such as trust, culture, history and identity (Farole et al., 2011; Rodríguez-Pose, 2013; Tomaney, 2013). These are key elements that can help in understanding the influence that materiality exerts in RE innovation processes. Natural resources, the built environment, and landscape (of energy), as we have stressed, are each influenced by narratives of identity, culture and tradition. This calls for a renewed attention to the practices and processes which underlie the making of these narratives.

Further theorisation in this direction will contribute to significant progress in our understanding of the influence that materiality exerts on RE innovation processes. However, without a balance of empirical research based on comparative case studies in different contexts, the progress of this new research agenda will be limited. The empirical implications of this new framework do need to be tested and scrutinised and the accumulation of empirical evidence across different national and international settings will without doubt help here. The authors are undertaking a comparative analysis of 5 regions across two different
institutional contexts (in Italy and UK). Although this work in progress, it has allowed significant empirical evidence to emerge about how the ways in which resources are mediated, constructed and mobilised can affect innovation processes and renewable energy deployment.

Last but not least, further work is required towards translating these insights into policy insights or recommendations. Nation-states remain committed to ambitious national renewable energy targets whose achievement depends on the successful implementation of projects at regional and local levels. This research shows that these can be the levels at which decisions about investments and the siting of RE power schemes and their infrastructures are crucial. The challenge is, therefore, to develop new tools of analysis for decision-makers that can facilitate the understanding of how actors, across different scales, are able to construct, influence and shape renewable natural resources.

6. Concluding remarks

The paper has sought to speculate theoretically about how a deeper engagement with the geographical concepts of materiality and the regional level could be useful in exploring low carbon RE innovation systems. The critical review of several related literatures and the arguments elaborated here have led to the development of a conceptual framework that, in contrast to much of the literature on innovation and systems innovation, foregrounds the importance and role of natural resources and the issue of materiality in explaining the uneven processes of low carbon RE innovation at the regional scale. We have argued that acknowledging the material underpinnings of the economic, social and political geographies of resource flows can help spur a renewed debate about the relationships between innovation processes- as they occur at different spatial levels that interact to shape the generation, application and proliferation of RE technologies- and the availability of natural resources, their physical and geographical occurrence and representation.

While the point of departure is the importance of resource availability in policy and practice debates, the intention is not to over privilege material explanation but rather to assert its place in understanding RE innovation systems. Engagement with the issue of materiality, and how resources can be both materially manipulated and socially constructed, it is argued, can improve our understanding of innovation processes and the spatial patterning, distribution and dynamics of RE innovation systems. The discussion presented here has proposed a set of arguments that builds on past and more recent theoretical frameworks and critiques that bring renewed attention to natural resources and how they are both physical
and social constructs. We have highlighted how a diversity of actors, networks and institutions located at global, national and regional levels are able to construct, influence and manipulate such resources.

This research invites scholars of the geography of transitions, and economic geographers in general, to further investigate how place-specificity and scale influence low carbon RE transition processes, we have also provided a framework that puts forward the regional level as a key level at which materiality and scale coalesce. While this paper represents a modest addition to previous research, we suggest that it offers a way forward for comparative empirical investigations that will enable similarities and differences across a range of places and scales to emerge, and perhaps act as a springboard for further refinement of the analytical approach proposed here.

¹ In the context of this paper it should be noted that Bathelt and Glückler (2011) have also called for attention to be paid to natural resources through their suggested relational economic geography perspective.

² This stands in contrast with much work in political ecology (for a review see Bulkeley (2005); Neumann (2009); (Robbins, 2012)) and the production of nature thesis, in which the mutual production of ‘society-nature’ relations has been central to research and analysis. Political ecology has been particularly effective at disclosing the complex ways in which communities use and value local ecosystems, the connections between landscapes and livelihoods, and the ways in which national and international policies can introduce alternative values and incentives for the management of ‘local’ resources (Robbins, 2012)

³ Treanor, J., (2009), Royal Dutch Shell to compensate shareholders for reserves scandal, in the Guardian

⁴ The natural environment has historically often been seen as a source of regional comparative advantage. Within the human geography literature, resource extraction (mining, oil and gas, etc.) is underpinned by the classical theory of comparative advantage in international trade as an agent of regional development (Gunton, 2003; Watkins, 1963). However, empirical evidence of natural resource-based development has led to considerable controversy (see for instance Bridge (2008) for a review of the two schools of thoughts that have emerged within the field).

⁵ In the Scottish case the rhetoric on renewable energy has been considered an extension of the key objective of gaining control over ‘Scotland's oil’ (Toke et al., 2013).

⁶ For the purposes of this work, institutions are characterized, following (Gertler, 2004: 7), as ‘formal regulations, legislation and economic systems as well as informal societal norms that regulate the behaviour of economic actors: firms, managers, investors and worker. (...) Collectively they define the system of rules that shape the attitudes, values and expectations of individual economic actors’

⁷ Such as general laws, labour market regulations, tax policies and subsidies, the education systems etc.
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