When the novelty fades – Socio-technical, spatial and temporal dimensions of regional energy transitions

Camilla Chlebna (camilla.chlebna@uol.de)

Department of Social Sciences, University of Oldenburg, Germany

Jannika Mattes (jannika.mattes@uol.de)

Department of Social Sciences, University of Oldenburg, Germany

Papers in Innovation Studies

Paper no. 2019/06

Centre for Innovation, Research and Competence in the Learning Economy (CIRCLE)

Lund University

Sölvegatan 16, S- 223 62 Lund, SWEDEN

http://www.circle.lu.se/publications

WP 2019/06

When the novelty fades – Socio-technical, spatial and temporal dimensions of regional energy transitions

Camilla Chlebna, Jannika Mattes

Abstract: Regional energy transitions are complex processes that are determined by manifold dynamics. We assign these to three core dimensions: the socio-technical, the spatial, and the temporal dimension, and integrate them into a comprehensive framework. We conceptualise the overall transition as unfolding in phases. The first three phases, 'initiation', 'expansion' and 'consolidation' are well established in the literature, and we supplement a particular focus on the social dynamics that constitute them. We also add a fourth phase, a period of 'fragile new order'. In this phase, socio-technical constellations seem to be well established and the novelty fades. This induces the danger of complacency amongst agents which reduces transition activities, and results in a tipping point. The transition may or may not proceed from this depending on the institutional arrangements and on how the regional agents cope with them. Drawing upon an in-depth case study of the Oldenburg region, we illustrate the dynamics of each phase and show how agents cope with the fragile new order. The observed adaptation processes include a resurge of informal constellations as well as diversification and even exit strategies.

Key words: Regions; energy; socio-technical transitions; phase model; strategic agency; tipping point

JEL codes: O33; P18; R11

When the novelty fades – Socio-technical, spatial and temporal dimensions of regional energy transitions

Camilla Chlebna and Jannika Mattes

Department of Social Sciences, University of Oldenburg, Germany

Abstract

Regional energy transitions are complex processes that are determined by manifold dynamics. We assign these to three core dimensions: the socio-technical, the spatial, and the temporal dimension, and integrate them into a comprehensive framework.

We conceptualise the overall transition as unfolding in phases. The first three phases, 'initiation', 'expansion' and 'consolidation' are well established in the literature, and we supplement a particular focus on the social dynamics that constitute them. We also add a fourth phase, a period of 'fragile new order'. In this phase, socio-technical constellations seem to be well established and the novelty fades. This induces the danger of complacency amongst agents which reduces transition activities, and results in a tipping point. The transition may or may not proceed from this depending on the institutional arrangements and on how the regional agents cope with them.

Drawing upon an in-depth case study of the Oldenburg region, we illustrate the dynamics of each phase and show how agents cope with the fragile new order. The observed adaptation processes include a resurge of informal constellations as well as diversification and even exit strategies.

Keywords

Regions; energy; socio-technical transitions; phase model; strategic agency; tipping point

JEL codes

O33 (Technological Change), P18 (Energy, Environment), R11 (Regional Economic Activitiy: Growth, Development, Environmental Issues, and Changes)

1 Introduction

Regional energy transitions are complex and constituted of multiple processes of change. Alternative socio-technological options are developed as old ones become obsolete, new actors get involved as old ones step back, and institutional arrangements get re-defined or new ones emerge. These are essentially social processes which take place at different geographical scales and over time. Theoretical engagement has been mainly concerned with the national level (Binz and Truffer, 2011; Binz *et al.*, 2014); nonetheless, the regional level plays a crucial role for transitions (Späth and Rohracher, 2010; Cooke, 2011; Mattes *et al.*, 2015; Gibbs, 2018). Furthermore, the aspect of time has received some attention through phase models of transition, but the role of the ongoing and necessary social dynamics at the level of concrete (inter)action remains under-considered (Rotmans *et al.*, 2001; Koehrsen *et al.*, 2019). Drawing upon existing phase models, applying them to the regional level and paying particular attention to the occurring social and institutional dynamics, we develop a heuristic model encompassing four phases, initiation, expansion, consolidation, and a fragile new order phase. We assert that this fourth phase, the fragile new order, deserves particular attention as transitions are not easily completed or 'finished'. On the contrary, their longer-term institutionalisation depends on the previous stages as well as on the enactment of the fragile new order. The importance of this transition phase is also acknowledged by recent contributions to the transition debate that focus on later periods of transition processes. They outline that old, suboptimal technologies need to be phased out as formerly novel solutions are increasingly established as mainstream technologies, and that interrelations and practice communities are institutionalised (Faller, 2016; Rogge and Johnstone, 2017; Markard, 2018b). We argue that it is this stabilisation on the regional level, involving technologies, agents and institutions, which crucially influences the further progress of the energy transition (cf. also (Fuenfschilling and Truffer, 2014). This is even more so as transitions unfold in waves of activities, and the fragile new order conditions if and how a next transition wave starts. In this perspective, the fragile new order forms the crucial link between the present and the next transition wave.

Our research question is therefore twofold:

> How do the dynamics between agents, technologies and institutions shape phases of regional energy transition processes? And what role does the fragile new order play for their continuation?

The remainder of this paper is organised as follows: In section 2, we devote some attention to existing studies of regional energy transitions by drawing on three core dimensions, the socio-technical dimension, the spatial dimension and the temporal dimension. We then introduce a comprehensive framework of regional energy transition phases and their social dynamics (section 3). The framework

addresses technologies, agents and institutions, and introduces a new phase which we refer to as *fragile new order*. We describe the key characteristics of this fragility and its relation to the further transition. After a short methodological section (section 4), an empirical case study illustrates the phases and their associated dynamics. We present evidence from recently completed fieldwork about a regional transition focusing on the dynamics surrounding the wind energy sector in Oldenburg, a medium-sized city in Lower Saxony, Germany. This demonstrates the important role of the agents' response to the fragility of the transition in the later stages (section 5). We finish with a brief conclusion (section 6).

2 Core dimensions of regional energy transitions

Regional energy transitions may be interpreted as sustainability transitions, defined by Markard *et al.* (2012) as "long-term, multi-dimensional, and fundamental transformation processes through which established socio-technical systems shift to more sustainable modes of production and consumption" (p. 956). Notably the focus of sustainability transition researchers tends not to be on the nature or definition of 'sustainability' but rather on the societal change involved. Such a societal change involves a "substantial shift" and affects "various realms of society" (Schneidewind and Augenstein, 2012, p. 18). In order to analyse these big and encompassing change processes, we propose to break down regional energy transitions into three core dimensions, (2.1) the socio-technical dimension (concerning the coevolution of agents, institutions and technology), (2.2) the spatial dimension (concerning space and scale), and (2.3) the temporal dimension (concerning the evolution over time). We proceed to argue the relevance of each in more detail below by giving a short overview of the relevant debates upon which this paper draws.

2.1 The socio-technical dimension: The co-evolution of agents, institutions and technology in regional energy transitions

As complex and encompassing processes of societal transformation, energy transitions are obvious examples of institutional change. Whilst institutional change may occur abruptly, it more likely involves a gradual process of transformation in which institutional rules are re-assessed, re-interpreted or re-fined (Mahoney and Thelen, 2009).

Whilst transition studies have made laudable contributions to the illustration of institutional change processes, they tend to remain vague on the role of agents in these processes: "While transition studies have traditionally emphasized the co-evolution of technology and institutions in socio-technical systems, the *interplay* between institutions and actors has gotten less explicit attention" (Fuenfschilling and Truffer, 2016, p. 301). In the last couple of years, researchers from very different

backgrounds have stressed the importance of analysing not only institutions and technologies, but the *interplay* between institutions, actors and their interrelations in the form of networks (Geels *et al.*, 2016). This shifts the focus from actors as passive recipients moving within the constraints predefined by the institutional context to active and decisive co-creators of new institutional settings. As 'embedded agents' (Garud *et al.*, 2007), actors decide about starting points and possible directions for institutional change, they accompany the process and consciously (or unconsciously) re-direct the taken paths at critical points of time.

Taken together, these contributions imply that energy transitions should be analysed as an interplay between technologies, institutions and actors – elements that have also been framed as central constituting elements of socio-technical systems (Schmid *et al.*, 2016). *Technologies* are created by actors, may be institutionalised in technological standards and rules, and are later drawn upon by actors, i.e. they provide opportunity frames for actors, similar to what Grillitsch and Sotarauta (2018, p. 9) outline as "opportunity spaces". *Institutions* constitute the rules of the game, the general framework and the reliable structures of the system and likewise impact these opportunity spaces (Fuenfschilling and Truffer, 2014). Individual and organisational *agents* enact the structures, stretch their limits, fill them with life and decide about the (dis)continuation of technological paths. They are thereby linked to each other and may form coalitions or networks.

We can conclude that a thorough understanding of energy transitions needs to focus on the socio-technical system, i.e. on the interplay between the involved actors, institutions and technologies. While actors are embedded in institutional frameworks, they likewise shape these institutions as institutional entrepreneurs (Garud *et al.*, 2007) or simply by following, questioning or bypassing the prevailing rules. Institutions, on the other hand, are hollow without actors bringing them to life. This means that the interplay between agents and institutions is at the core of any transition process, always in interdependence with technological development, determined by constraints and possibilities resulting from spatially and temporally differentiated capacities. Both will be outlined in the following sections.

2.2 The spatial dimension: The relevance of small-scale regions in energy transitions

The debate on sustainability transitions in general and on energy transitions in particular originally had no spatial focus. Recently, however, it is widely agreed that transition processes are embedded in locally specific institutions, infrastructures and natural environments, and are therefore fundamentally place-dependent (Coenen *et al.*, 2012).

In a review of key contributions to this debate, Hansen and Coenen (2015) offer more detail on *why* energy transitions are so place dependent. They summarise five key facets of place specificity

commonly highlighted in the academic debate: First, *urban and regional visions and policies* are central for energy transitions and co-determine the evolution of transition processes. Actor coalitions are commonly rooted locally, and the physical infrastructure that goes along with transitions tends to be decentralised (Späth and Rohracher, 2010; Hodson and Marvin, 2012; Essletzbichler, 2012). Second, *informal localised institutions* are strongly rooted in particular localities. They form backbones, particularly for niche evolution, that cannot easily be transferred to other localities (Coenen *et al.*, 2010; Smith, 2007; Raven *et al.*, 2012). Third, the *local natural resource endowment* is decisive for the available transition pathways. It stimulates investment and influences which renewable energy technologies can be installed in particular locations (Bridge *et al.*, 2013). Fourth, the *local technological and industrial specialisation* provides conditions for the development of innovations and for political agendas. This relates to geographical clusters, particularly to specialised knowledge spill overs (McCauley and Stephens, 2012; Grillitsch and Hansen, 2018). Finally, *consumers and local market formation* are highly localised as engaged end-users and geographical proximity contribute to consumer decisions. Regulatory arrangements, but also engaged end-users particularly depend upon geographical proximity in young markets (Binz *et al.*, 2012; Dewald and Truffer, 2012). Taken together, these five aspects of locality underline how multifaceted and significant place dependency of energy transitions is (Hansen and Coenen, 2015).

If acknowledging this place dependency, much of the literature on sustainability transitions hitherto has implicitly taken the nation state as level of analysis (Binz *et al.*, 2014). More recent contributions, however, highlight the particular importance of the regional level for energy transitions (Gibbs, 2018; McCauley and Stephens, 2012), and a discussion on the regional and local dimensions of energy transitions has emerged (Mattes *et al.*, 2015; Coenen and Truffer, 2012; Truffer *et al.*, 2015). Dijkstra and Poelman (2016) recommend that the territorial units used reflect the geographical distribution of the phenomena under investigation: renewable energy sources tend to be more decentralised than the previous energy system, and therefore a more place-sensitive research perspective is required (Klagge and Brocke, 2012; Sperling *et al.*, 2011). Gibbs (2018) suggests a relational perspective to understand how the involved actors go beyond the local level to operate at multiple scales: in countries like Germany with strong federal governments, regions tend to play a particularly strong role in coordinating strategic planning and innovation policy (e.g. cluster initiatives). Regional actors and institutions have a critical role in translating abstract national and supranational visions of sustainability into concrete reality and are essential for "advancing socio-technical change on the ground" (Gibbs, 2018; McCauley and Stephens, 2012, p. 214). This implies that the importance of regions for energy transitions is generally accepted, yet scholars tend to remain vague on what the 'region' really is and on what constitutes its particular relevance (Gibbs, 2018). On this matter Paasi *et*

al. (2018) suggest that "regions are not out there to be found; instead there are different ways of seeing 'the region' and their making" (p. 5).

This paper focuses on the level of small-scale regions.[1] At the same time, although they are not at the core of the present paper, we are aware of the multi-scalar relations of local agents and the embeddedness of their activities in wider (innovation) systems (Binz and Truffer, 2017; Fuenfschilling and Binz, 2018).

We can conclude that energy transitions are place-dependent and that regions provide a valid starting point for analysing energy transitions. The following section illustrates the importance of the temporal dimension.

2.3 The temporal dimension: The role of time for regional energy transitions

Socio-technical transitions are explained as path-dependent phenomena that undergo 'innovation journeys' (Geels *et al.*, 2008) over an extended period. Several authors have drawn explicit connections between transitions and phases or waves that occur in these processes (e.g. Rotmans *et al.*, 2001; Koehrsen *et al.*, 2019; Sovacool, 2016; Jedelhauser and Streit, 2018). Rotmans *et al.* (2001) distinguish four phases as part of an overall process of transition. Initial *pre-conditions* are followed by a *take-off* phase, where change gets underway. Then, in the *breakthrough* phase, "visible structural changes take place through an accumulation of socio-cultural, economic, ecological and institutional changes that react to each other" (Rotmans *et al.*, 2001, p. 17). During the *acceleration phase*, these changes diffuse and start to be embedded into the general context. Finally, in the *phase of stabilisation*, a dynamic equilibrium is reached. Whilst Rotmans *et al.* (2001) acknowledge that "[d]ifferent social processes come into play during the various phases" (p. 17), they do not offer much detail on what exactly these social processes are and how they shape the overall transition.

Similarly, but spatially specific, Jedelhauser and Streit (2018) analyse different phases of energy transition in the Allgäu region in Bavaria. They combine the outlined phase model (Rotmans *et al.*, 2001) with institutional work (Lawrence and Suddaby, 2006) to describe how a region in Southern Germany proceeds from a *pioneering phase* to a *networking and professionalization* phase, an *acceleration* phase, a *consolidation* phase and finally, a *period of stagnation*. Relating to institutional work (Lawrence and Suddaby, 2006), they describe each phase of regional energy transition primarily as a process of the 'creation, maintenance and destruction of institutions'. With this approach, the authors are able to highlight the dynamics that occur between agents and institutions. The interplay

[1] Small-scale regions means taking NUTS3 level regions as a starting point. Regions are hence bigger than small cities, but notably smaller than federal states. The actual delimitation is more dependent on social habits than on the administrative boundaries.

between individual agents as well as the embeddedness of the regional transition in the wider transitional context is not in the focus of their study.

Also Koehrsen *et al.* (2019) explicitly derive their three phases of regional energy transitions from an evolutionary perspective. Building upon Tushman and Rosenkopf (1992), they refer to an *initiation* phase, an *expansion* phase and a *consolidation* phase. In two regional case studies, they show how individual actors drive transition processes in the initiation and to some extent also in the expansion phases, while particularly consolidation is shaped by more reliable structures and institutions.

In the following, we build upon these three approaches. We draw upon the phase dynamics brought forward by all of them. Following the suggestion of Jedelhauser and Streit (2018) and Koehrsen *et al.* (2019), we add an explicit focus on social interactions between actors and institutions. Moreover, we introduce an additional phase where a *fragile new order* emerges which constitutes the pre-conditions for the next transition sequence.

Having explained how the socio-technical, the spatial and the temporal dimensions matter in regional energy transitions, we will now present a phase model that acknowledges all three dimensions, i.e. which considers the socio-technical dynamics, the spatial dynamics and the temporal dynamics. The model aims not only to describe the inter-related processes that lead up to a fragile stabilisation. It also puts a spotlight on the particular characteristics of this latter state that entails both stability and fragility. This allows us to formulate a proposition on what is required for the continuation of the regional energy transition.

3 A phase model of regional energy transitions

We have shown that the regional level provides a relevant setting for energy transitions, and that these transitions are dynamic processes that undergo phases. Relatively neglected remains what happens after these phases have passed and 'when the novelty fades'. In the innovation process, new technologies are continuously integrated into existing systems, are gradually routinised and become taken for granted (Martin, 2010; Geels, 2002, 2004). The nimbus of novelty hence fades as time passes, and innovations are perceived as being established. The same is true for transitions: As the change process has been completed, an apparently stable situation occurs. This implies that cautious stability is an inherent part of any innovation or change process (Fuenfschilling and Truffer, 2014); however, we know surprisingly little about it. Only some very recent contributions underline the importance of focussing on this phase of apparent stabilisation and its potential consequences and outline the role of maturation, routinisation and the possibility of institutional misalignment in late transition phases (Markard, 2018a).

Adopting this focus is justified for two key reasons. First, many of the technologies that constitute energy transitions are currently in a phase of apparent maturation, which implies that we are increasingly unable to describe empirical phenomena with the existing theoretical focus on the emergence of the new (cf. also (Markard, 2018b). Second, the outlined routinisation is neither self-evident nor straightforward: the emerging fragile new order, as we call it, plays a crucial role for the continuation of transition dynamics. And as the emerging order is still fragile, it does not necessarily prepare the ground for the next transition wave. Instead, it may just as well lead to stagnation or even induce steps backwards.

Building upon and combining elements of the different approaches outlined above, we distinguish between four transition phases, *initiation*, *expansion*, *consolidation* and *fragile new order* inherent in regional energy transition processes. Based on a socio-technical perspective, we focus on agents and institutions that constitute the four phases as units of our analysis. Regarding agents, we outline which individual and collective actors are involved, their interrelations, how actors coevolve with the emerging technologies and at what spatial scale they are active. Related to institutions, we address informal and formal institutionalisation.

First, transition processes undergo an *initiation phase*. It is where path creation takes place and besides the prevailing traditional socio-technical constellations, new possibilities are being considered and experimented with. This phase is characterised by the driving role of actors that initiate and carry out small-scale activities (Garud and Karnøe, 2003; Simmie, 2012). The novel solutions are not the dominant technology, but usually complement the prevailing regime. Actors proceed rather unconnected from each other as they have not yet had the chance to form stable interrelations. If they connect, personal contacts are crucial. Evidently, formal institutions have not been established, and common practices and routines only slowly emerge. In this sense, initiation is a matter of individual, small and cautious steps towards change that remains highly localised.

Second, in the *expansion phase,* socio-technical alternatives spread, the public awareness of the new technology increases, and the institutional order starts to adapt accordingly. There is a rising number of actors, activities and collaborations that experiment with different aspects of the new socio-technical possibilities. This also goes along with a more dominant, visible and accepted position of new socio-technical solutions in the region. Competition between the new and the existing technologies increases, and existing activities may start to upscale and the spatial scale can slowly expand. Based on the increasing interaction, collaboration between actors intensifies and some interconnections are being stabilised in order to exploit potential synergies. This goes along with conflicts and frictions on possible directions of change, or, to frame it in accordance with Tushman and Rosenkopf (1992), with an increasing selection and sorting of possibilities. Increasingly, common institutions emerge. This

refers above all to shared routines and practices, while formal institutionalisation takes place only cautiously.

Third, in the *consolidation phase,* the driving actors are commonly known and know each other, and the technological solutions now seem to be mature and actor constellations seem stable. The new socio-technical possibilities cease to belong to a mere niche and are – at least in a defined area or region – slowly integrated into the dominant regime. This may involve fierce power struggles between already established and new actors. As new actors gain power, they can also apply the new technologies at a wider scale, which is how the new technology begins to transcend the regional level. Actor relations tend to become more stable and coordinated, and the interaction between and within actor groups follows well-defined rules. This is also facilitated by the institutions that have emerged in the meantime: shared rules and perceptions are well known, and organisations that structure the emerging field add a formal institutional layer that reduces uncertainties (cf. also (Fuenfschilling and Truffer, 2014). The newly established routines and institutions are being stabilised and put onto more durable ground. Forward planning, the fixing of long-term objectives, and stronger coordination of the activities contributes to (at least short-term) stabilisation.

This consolidated, but not yet settled system passes into the *fragile new order*. What were previously new solutions lose their novelty appeal. They are increasingly taken for granted and complacency can creep in amongst agents. A tipping point occurs at which it is decided whether the next sequence of initiation, expansion and consolidation begins. This induces that two basic development options emerge. First, the transition process is driven forward and continues. Actors are well established and prove their flexibility, the introduced technologies may be adapted and diffuse further. The system is perceived to be stable and its persistence is taken for granted. Second, the tipping point can just as well lead to stagnation because the recently established, still fragile order proves to be insufficiently stable to support new activities. This means that the progress of the transition may be protracted and to some degree even reversed. Actors may lose motivation because of complacency, which potentially re-empowers formerly dominant actors who may try to shift the order back to the pre-transition situation. If the introduced technologies do not prove to be adaptable and flexible, they may be turned down eventually. Similarly, well-running actor coalitions may become worthless if too many actors disengage. In this way, the fact that the system is perceived as established and taken for granted can just as well endanger the cautiously established order.

Table 1 summarises the core characteristics of each of the four phases introduced above. It has to be stressed that the differentiation between the phases is of course ideal-typical and serves as a heuristic towards a better understanding of the social dynamics which determine regional transition processes.

<table>
<tr><th></th><th>Agents</th><th>Institutions</th></tr>
<tr><td rowspan="3">Initiation</td><td>Driving actors and activities:
- Distributed activities by individuals or small communities, often private with limited awareness of others</td><td rowspan="2">- Common practices emerge, but little agreement on their form or on shared rules (not yet institutionalised)
- Reliance on local personal contacts but no formalised structures</td></tr>
<tr><td>Socio-technical coevolution:
- Actors regard socio-technical novelties as complementing the prevailing technological regime</td></tr>
<tr><td colspan="2">Space and scale:
- Initiatives tend to be small scale and isolated
- Mostly locally rooted agents with clear home-based mission (local leadership)</td></tr>
<tr><td rowspan="3">Expansion</td><td>Driving actors and activities:
- Additional activities and agents emerge as technological solution diffuses
- Conflicts and frictions between agents about direction of change</td><td rowspan="2">- Established routines and stable practices are amended in support of new technologies and agents
- Routinisation substitutes ad hoc decision-making and personal contacts
- Increasing interaction and cooperation amongst agents from different initiatives in the region
- Mainly informal interrelations, but also cautious emergence of formal structures</td></tr>
<tr><td>Socio-technical coevolution:
- Competition both between existing and emerging technologies and agents – as well as amongst emerging technologies and between agents</td></tr>
<tr><td colspan="2">Space and scale:
- Upscaling of existing initiatives
- Spatial reach may expand from local to regional level</td></tr>
<tr><td rowspan="3">Consolidation</td><td>Driving actors and activities:
- Established actors who increasingly interact and collaborate locally and regionally
- Pioneering agents either move on or embed themselves in emerging institutional structures</td><td rowspan="2">- New socio-technical constellations stabilise as shared rules and perceptions are established amongst the participants
- Homogenisation of aims and goals facilitates harmonious co-existence of variety of agents in the region
- Informal coordination formalises into organisations which communicate on behalf of the sector</td></tr>
<tr><td>Socio-technical coevolution:
- Coordination and bundling of activities to exploit synergies
- Recently established solutions perceived as having become ‘regime’</td></tr>
<tr><td colspan="2">Space and scale:
- Diffusion of recently introduced technological solutions
- Uptake widening beyond region</td></tr>
<tr><td>Fragile new order</td><td>Driving actors and activities:
- Established actors and activities
- Some agents withdraw and new ones may still emerge
- Risk of complacency as agents take transition as a matter of course</td><td>- Newly established shared rules and practices need to provide the necessary stability whilst continuing to allow superior, new solutions to be developed</td></tr>
</table>

	Socio-technical coevolution: - Enthusiasm amongst users and consumers may drop as "novelty" fades - Adaptability and flexibility crucial: strategies include exploration of new markets nationally and internationally, collaboration, integration with other sectors	- Previously novel technologies are perceived as mature both regionally and nation-wide - Institutions around organised interaction stabilise but are weakened if too many regional agents disengage - Pro-active policy support may decrease or even cease - Connections and inter-dependencies between communities and amongst sectors become essential
	Space and scale: - Pioneer region's role as vanguard diminishing - Need to define role of region within (global) industry	

Table 1: Phases of energy transition and their core characteristics (own representation)

As the outlined phases are interdependent with each other, the fragile new order is constituted and prepared through the initiation, expansion and consolidation phases. Once transition processes have entered a *fragile new order*, the newly established agents find themselves needing to adapt their strategies to persist. They may seek collaboration with other agents, explore new markets (e.g. abroad) or seek integration with other sectors (Frangenheim *et al.*, 2018). These options are among the core strategies that ensure the continuation of the transition process and create the all-important stability to sustain further activity. These considerations lead us to the following proposition: *The institutional arrangements and the way agents cope with them in the fragile new order condition whether a next wave of transitional activity can occur or not.* This means that the development beyond the tipping point is pre-conditioned by the prior set-up of the socio-technical system as well as by the way actors and institutions enact the fragile new order.

In this sense, the response of the involved agents and institutions to the tipping point that goes along with a *fragile new order* decides about the next sequence of the transition process, akin to what Lee and Malerba (2017) describe as the response of the 'system elements' to the opening of a 'window of opportunity'. If we regard the overall transition as an ongoing process that unfolds in waves of activity, it comprises the invention and innovation of new technologies, ideas and practices as well as the institutionalisation of these in networks and practice communities (Faller, 2016). Transition waves hence are constituted of consecutive S-curves, a well-established conceptualisation in science and technology studies (Sovacool, 2016, p. 204, cf. table 1 in this paper): again and again, new socio-technical possibilities emerge, are being institutionalised, and result in temporary stability – before they are questioned and may give way to new alternatives.

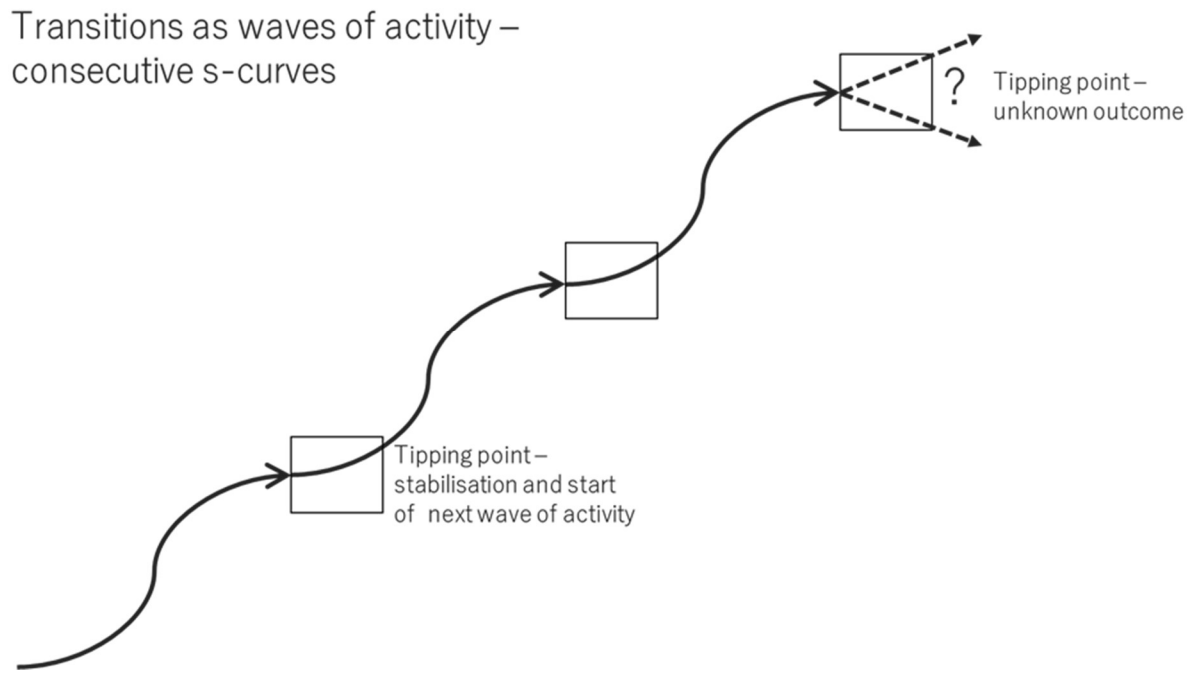

Figure 1: Transition as S-curve: sequences of transition waves (own depiction, inspired by Sovacool (2016)).

To summarise, regional energy transition is a complex, evolutionary process that continuously unfolds in consecutive waves of activity. The described process is a combination of planned, strategic, coincidental as well as unplanned emergent elements (Rotmans and Loorbach, 2009). In the following, we will illustrate the outlined change and stabilisation processes empirically and assess the proposition that *the institutional arrangements and the way agents cope with them condition whether a next wave of transitional activity can occur or not.* Concluding, the intention is to show how the suggested framework can help to understand energy transition at the regional scale more precisely.

4 Methodology

Above we have presented the relevant academic debate in a partially systematic but largely narrative literature review structured by themes. This seems appropriate as we synthesise information from more than one theoretical discipline and perspective. In the following, we elaborate on our chosen methodology for an empirical illustration. We draw on evidence for our framework from a single case study, carried out in and around the city of Oldenburg in Lower Saxony in Germany in 2018.[2] As our aim is to provide a thick description of the social dynamics involved in regional energy transitions, a

[2] This paper forms part of the Emmy Noether group REENEA which is running from 2018 to 2022 at the University of Oldenburg. The project investigates the role of social processes in energy transitions on the regional level. We kindly thank the DFG for funding the project (grant no. 316848319). Details on the project can be found at www.uol.de/orginn/forschung/reenea.

single case study is the most appropriate type (Yin, 2009; Sovacool *et al.*, 2018). Our case study focuses on transition in just one sector, wind energy, in order to profoundly understand the inherent dynamics of socio-technical change.

In the course of the case study, we carried out 26 semi-structured expert interviews in the region of Oldenburg. We interviewed individuals either directly or indirectly involved with the wind energy development (politicians, firm representatives, scientists etc.). Interviews lasted between 50 and 120 minutes. They were all conducted based on an interview guide which covered the role of the interviewees and their organisation, the interviewee's relation to other actors in and beyond the region, the past and current energy transition (with a particular focus on wind energy) in the region and beyond, the role of the region for this transition process, and conditions for change. The interviews were recorded, transcribed and coded with the help of the qualitative analysis software MAXQDA. Analytical categories ('codes') were developed both based on the conceptual framework and 'in vivo', i.e. inductively from the text. Besides the interviews, we used participant observation to evaluate the micro dynamics of regional actor constellations. We took part in networking events and in round tables on the further wind energy development in the region. Completed by a detailed document study, the insights resulted in an encompassing and systematic case study.

In the following, we will draw upon the example of Oldenburg to illustrate the socio-technical, spatial and temporal dynamics of a transition process and its tipping points, and to outline the specificities of the fragile new order.

5 An empirical illustration: The Oldenburg case study

Given our focus on wind energy activities, the region of Oldenburg provides an excellent case. Based on its exceptional wind conditions, the wider Oldenburg region is one of the pioneering wind regions in Northern Germany. Whilst there is only one small wind park of four wind turbines within the actual city of Oldenburg, its direct surroundings, the wider North West region and also Lower Saxony have very high rates of installed wind capacity (Agentur für Erneuerbare Energien, 2018). In the following, we will illustrate the regional transition process following the outlined phases of initiation, expansion, consolidation and fragile new order, for each addressing the socio-technical, the spatial and the temporal dimension as outlined above.

5.1 Initiation phase (ca. 1990 – 2000)

The first step towards the establishment of renewable energies was the first feed-in mechanism, the Stromeinspeisungsgesetz of 1990. Before that, wind energy only played a marginal role in the region

and was restricted to agricultural purposes. The increasing political support in the 1990s initiated the emergence of an actual industry (OL14_owners,operators&utilities).

This earliest period of wind energy activities in the Oldenburg region was characterised by distributed activities of singular, highly innovative **agents** that one could call 'visionaries'. The following quote illustrates the exceptional position of such a 'visionary'.

> *"[In the mid 1980s] [the visionary] joined our seminar […] and said: "In ten to fifteen years we will have wind turbines everywhere around here." And we just sat there and thought: "What a nutcase."" (OL08_science&education)*

In the following years, these visionaries remained not only in the sector, but also in the **region**. They spun out their own firms from the university and started to contribute to the exceptional social micro-climate for renewable energy that characterises the region.

> *"Everyone who played a role back then has stayed around […] The university has been, … you can't quite call it a catalyst, it is more like a germ cell. Actually you can say it was the birth place of all of those firms." (OL08_science&education)*

As the quote shows, the University of Oldenburg played an important role in establishing a regional **network**. Even though most experts expected wind energy to remain at best a minor supplement to traditional sources of energy, the university started offering a course on renewable energies. Very early on, it hence occupied a niche: very few other academic institutions would engage with this area scientifically at the time.

> *"You just couldn't imagine that it was even technologically possible. […] Fortunately they [the university] had this perseverance to establish this subject on the long run and to build a reputation." (OL02_ science&education)*

This specialisation was decisively driven by the fact that as a small university with relatively few resources, Oldenburg University was not able to immediately compete with larger, traditional university cities and institutions like a leading technical university. Instead, it needed to occupy promising niches.

> *"[…] Oldenburg was one of the first locations engaging with research on renewable energy. This is driven by the fact that it is a small to mid-sized university. You will never have the resources to tackle the big core topics that really big universities occupy […] You are always forced to find subjects, where you don't need 200 researchers and 30 professors just working on this one subject from day zero to just be on a par with the others." (OL02_ science&education)*

The outlined dense connections between the early inventors, engineers and pioneers formed a reliable structure without any need of **institutionalisation**. The actors shared an ideological base politically left of centre and a strong affinity to the growing international environmental and peace movements. One interviewee, now the CEO of his own company, recalls how his PhD supervisor changed into a private company before he finished, and how they continued their collaboration through their current

companies (OL18_service). These informal networks persist and are responsible for the particular dynamics of the wind energy sector in the region.

We can conclude that the initiation phase is a loose period of individual activities, whereby actors are linked via their relation to the university. Based on its locality (high wind speeds) and based on the need to occupy a niche, a regional scientific focus on wind energy and renewables emerges. Via technical innovations, spinouts and start-ups, this soon spills over into the local industry.

5.2 Expansion phase (ca. 2000 – 2008)

In the expansion phase, wind energy became better understood and the connected technology matured and diffused. Not only new individual **actors** entered the scene, but also organisations established the topic in the region. An important organisational actor is the university's scientific research centre on wind energy founded in 2003.

> *"I do think everything was right that we did but of course this alone is not enough. The historical circumstances which led to wind energy becoming popular at the time meant that financial questions [e.g. to initiate organisations] became quite easy." (OL08_ science&education)*

Further important new organisations are a start-up centre and an energy network. Both have a particular focus on energy technology and act as boundary organisations (Koehrsen, 2017). They host the emerging companies and activities, back them up with administrative support and bundle them into a coherent political voice that is also able to speak to federal and national state level. This entailed a certain degree of **institutionalisation**, whereby particularly regional politics were interested in better integrating disparate agents in the field of renewable energy. Actors from science, but also politics and a regional energy provider could increasingly rely on structures for their connections (e.g. OL08_science&education, OL24_politics&administration).

This **socio-technological co-evolution** further gained momentum through the EEG (renewable energy law). Wind energy related activities were significantly expanded and upscaled, and an industry could form (Ohlhorst, 2009). This period of nationally supported growth was an important development impulse for the wider region of Oldenburg. The region started gaining its reputation as a centre of expertise. Politicians, but also scientists from Oldenburg were involved in national initiatives to foster this new industry.

This shows that the **spatial reach** of Oldenburg's wind agents expanded as the wind technology improved. After establishing projects locally, they applied the developed knowledge to other locations, initiating their diffusion across the whole of Germany.

> *„It started locally, […] with their own land, about 20 years ago and just developed bit by bit. And once they have accumulated the know-how they can just do it everywhere." (OL05_service)*

Based on technological progress, also less optimal locations could now be exploited in an economic manner. This expands the technological reach even further.

> *"Fortunately the technology has developed such that we can now economically exploit land locked locations by using larger rotor diameters. This means we travel further both towards the East and the South of Germany to lower wind speed locations and carry out projects further away." (OL23_owners,operators&utilities)*

We can conclude that the expansion phase is characterised by a high growth of individual and organisational actors. These are increasingly becoming connected and also stabilized in formal institutional settings, whereby boundary organisations play a decisive role. The spatial reach increases in line with technological progress as the region gradually establishes itself at the forefront of wind energy research.

5.3 Consolidation phase (ca. 2008 – 2015)

From the end of the 2000s onwards, wind energy technology was increasingly perceived as a mature technology and the industry was regarded as well established. The technology had widely diffused and was being applied even by incumbent energy providers that now had their own in-house expertise in renewable energy.

> *"I think this makes a big difference in the area of energy systems. Ten years ago we would have said [about the big energy providers]: "You have no idea!" and we would have been right! This isn't true anymore. […] But this is good for us [scientific institute] too, because now you can talk to these people. They understand you, which wasn't the case then." (OL08_science&education)*

Regarding the **socio-technical co-evolution**, wind energy technology became firmly established and accepted as part of the 'regime' (Geels *et al.*, 2017) in the wider North-Western region of Germany. Most firms strengthened their interaction and were highly aware of their position in integrated systems of renewable energy provision. The energy network, which communicated on behalf of the energy sector in the region, was now well established. Many allocated firms and organisations associated with renewable energies were members and considered it an important platform to meet, to gather information about sector developments and to work on collaborative projects with the explicit aim to sustain the sector in the region in the future (i.a. OL15_service; OL16_service). Agents in the region of Oldenburg regarded this interaction as a self-evident necessity.

> *„If you want to stay at the forefront of technology you are just forced to work together with other disciplines. […] No-one doubts that any more today." (OL02_science&education)*

The diffusion and the broad acceptance of the need for a significant shift towards sustainability in energy generation meant that the sector gained a certain stability. Interviewees identify this process of **institutionalisation** as a key characteristic of this phase.

"I think an important difference is the stability. […] That you don't need to worry […] whether the people that you qualify will find work in renewable energies in five years." (OL06_service)

This period is further characterised by the increasing **spatial diffusion** of wind energy technology across the whole of Germany and internationally. The region of Oldenburg achieved vanguard status as a lighthouse centre of excellence in wind energy research worldwide and as a model region of energy transition.

"You can see it in the statistics: The relevance of the sector and the very high rate of renewable energies already connected here. We are certainly frontrunners not just in Germany but also in the whole of Europe." (OL19_trade_associations&unions)

In conclusion, the consolidation phase is characterised by stabilisation, institutionalisation and the emergence of reliable interaction patterns among the involved agents. The spatial reach increases and the region of Oldenburg establishes itself as a wind energy innovator with an international reputation.

5.4 Fragile new order (since ca. 2015)

Most recently, the regional dynamics have started to change, comparable to what Markard (2018b) describes as second phase of energy transition. While a high dynamic is still observable, the outlined stability seems to be endangered as political support decreases. As the industry is forced to adapt to a changing environment, the key discourses change and some **agents** show signs of complacency. Some of the most established agents cease to engage much with the renewable energy network or disregard it altogether.

„Nowadays, they just talk. Tell me one project, which they actually conducted. […] I don't think much of it." (OL14_owners,operators&utilities)

Some agents even claim that the sheer size of the network may hinder its effectiveness, which shows that **institutionalisation** is not an asset per se.

"This network has become too big and watered down to be really effective at all." (OL18_service)

Regarding the **socio-technical co-evolution** the regional industry can still draw upon favourable natural conditions and is hence in a position to think pro-actively about adaptive strategies in response to changing policy frameworks and the increasing global competition. New strands of thought enter the debates, e.g. the potential coupling of the energy sector with other sectors like mobility receives considerable attention in the region. Because of the availability of underground caverns there are also research efforts on 'Power-to-Gas', i.e. the conversion of wind energy into hydrogen and its storage underground (OL10_boundaryorganisation, OL21_science&education). While all of these strategies strengthen and embed the established wind energy activities, other strategies potentially endanger the stability of Oldenburg's wind energy transition: In order to be more independent of the uncertain

political framework conditions in Germany, firms from Oldenburg increasingly expand their activities geographically and explore new markets elsewhere.

> *"We observe that many competitors, but also producers, position themselves stronger abroad or expand their portfolio with other value-added steps and technologies. There are the same developments that we have seen a couple of years ago: The solar sector has broken down, you cannot save that any more. But also biogas is […] looking for alternatives. […] These deviations that we know from other sectors are now also affecting wind energy. […]" (OL23_owners,operators&utilities)*

All these activities show that agents are well able to cope with the challenges of the fragile new order. At the same time, the observed coping strategies may potentially weaken Oldenburg's wind energy transition. Similarly, the high **spatial reach** may start endangering the local industry, while at the same time, the high level of available knowledge and expertise in wind energy that is available in the region still backs up Oldenburg's position, and the global industry may continue to rely on this knowledge. Still, the globalising industry forces the region to reconsider its role. All the above-mentioned strategies form part of the formation of a new role for the region.

> *"Now we have this issue, based on the changed policy framework and the tendering system, we don't have a lot of projects going forward. It is noticeable that there is a dent. Not a lot of new projects are coming in. Thus, things have shifted a bit for us [away from the region]." (OL25_service)*

At the same time, wind energy in Oldenburg continues to rely on strong linkages between various agents. Particularly the **informal** dynamics facilitate new collaborations, also in response to changing circumstances.

We can conclude that the fragile new order in Oldenburg results from the three preceding phases, but also comes with completely new challenges and dynamics. On the one hand, the seemingly established institutionalisation starts to crumble as actors find alternative strategies to cope with the difficult political framework conditions. On the other hand, informal relations in particular remain reliable structures to maintain a high level of activity in the region. Even though the region is apparently well prepared for a new transition wave, the current dynamics in the wind sector clearly illustrate how fragile and uncertain the further energy transition is.

5.5 Discussion of the case study

The empirical account of the Oldenburg region illustrates the dynamics that characterise different phases of energy transitions. In the initiation phase, we find few agents who initiate first wind energy projects. Contrary to the theoretical expectations, these are already well connected via informal, personal relations: most of them emerge around a university that frames their common interests. While the spatial reach is very restricted here, it increases in the expansion phase. Both agents and technologies mushroom, prove themselves and form a promising, politically supported niche.

Boundary organisations start to structure and institutionalise linkages, and the emergent stability is further backed up in the consolidation phase. Wind energy has become an established sector, and the region of Oldenburg holds a leading position. Agents cooperate not only on their core topics, but start crossing professional and sectoral borders to increase the reach of their technologies. The spatial reach also increases further to include not only national, but also international partners and markets. Finally, in the fragile new order, we find the expected signs of complacency and uncertainty. In the established sector and with ceasing political support, the value added of large institutional structures is being questioned. Actors fall back on personal networks which they have established in the previous phases, but also seek certainty outside the regional and sectoral settings. While this may endanger the regional structures, the current impression is that particularly the established personal networks and the unagitated way of coping with structural change provide a good basis for the future of the Oldenburg region. This underlines that the fragile new order phase is decisive of whether a new transition wave is triggered or not, and that even a well prepared region may struggle at this stage.

Table 2 summarises the key findings from the case study in Oldenburg according to our framework.

	Agents	***Institutions***
Initiation	*Driving actors and activities*: - Few visionaries	- Personal relationships especially originating from university shape the regional sector development
	Socio-technical coevolution: - Wind energy not taken seriously, university's activities in RE research regarded as marginal	
	Space and scalarity: - RE research is a welcome niche to focus on for a small university with limited resources	
Expansion	*Driving actors and activities:* - Emergence of manifold actors - Creation of boundary organisations	- RE network facilitates a more structured integration of regional agents
	Socio-technical coevolution: - Wind energy as a promising niche	
	Space and scalarity: - Regional agents have accumulated know-how which they begin to apply nationwide	
Consolidation	*Driving actors and activities:* - Formerly resisting incumbents like energy providers now have in-house expertise in RE	- Sector accepted as fundamental part of the energy system of the future with strong political support → stability
	Socio-technical coevolution: - Wind energy seen as part of regime - Increasing focus on interorganisational and interdisciplinary cooperation	
	Space and scalarity: - Use of wind technology has diffused nationally and globally, region seen as vanguard in technology	
Fragile new order	*Driving actors and activities:* - Some actors disengage from regional networks	- Established collaborative regional culture makes it easier for regional firms to adapt - Regional network loses focus → Informal contacts gain importance against formal structures again
	Socio-technical coevolution: - Regional firms seek better integration with other sectors to improve resilience and explore new technologies and markets	
	Space and scalarity: - Oldenburg appears able to retain its role as centre of excellence in wind research, but is simultaneously endangered by shifts away from regional and technological focus.	

Table 2: Phases of wind energy transition in Oldenburg

6 Discussion and Conclusions

This paper claims that we need to put social dynamics at the centre of attention if we want to understand the socio-technical nature of energy transitions properly. It suggests a framework that draws upon established phase models and interprets them with a special focus on agents, institutions and spatial dynamics. In particular, we claim that the emerging order is not necessarily a safe and stable new system, but can be understood better as a 'fragile new order' that may either support new transition dynamics or not, as the novelty fades and political support ceases – depending on the actor constellation and on the occurring dynamics. Agents and institutions shape the different phases of the process differently, whereby the importance of agents seems to decrease slightly as the institutionalisation of new technologies and actor constellations offers an alternative coordination mechanism. In the course of time, institutions take over part of the coordination process previously fulfilled by agents. The regional institutional arrangement hence reassembles, forming a new temporary equilibrium. In the fragile new order, however, these institutions may not fit the new dynamics of a more established industry and changing framework conditions. Therefore, informal connections regain importance: they stabilise the environment and prevent agents from moving away from the region and out of the sector. At the same time, the spatial reach of the activities widens in line with increasing institutionalisation. While many companies maintain their stable base in the original location, the diffusion of their technologies allows entering new markets and targeting new customer groups.

Regarding the outlined fragile new order, there are three key factors that determine its inherent character: (1) The recently introduced technological solutions are increasingly perceived as mature and lose their novelty appeal. This means that political support as well as the buzz around the involved technologies decreases. (2) Established agents as well as consumers may experience complacency in the face of progress already made. There is the expectation that the process will continue anyway. This may, however, go along with decreasing engagement and hence slow down the transition. (3) A tipping point occurs from which the transition may or may not proceed depending on the institutional arrangements and on how the regional agents cope with them. This open nature of the fragile new order underlines its special importance and why it deserves particular attention even though the technology is well advanced and seems to be established at the time.

From the conducted analysis, we can draw several conclusions. For scholarly research, we have particularly underlined the importance of social dynamics in understanding regional socio-technical change. Technological evolution goes along with changing relations between agents and institutions, the technologies' spatial reach changes, as well as the networks agents are organised in. It is important

to understand the involved phase dynamics and essential to analyse them beyond apparent stabilisation.

Second, for policymakers, our findings highlight the danger of ceasing political support as the novelty of a technology fades. The time needed for a transition process to stabilise should not be underestimated. We have shown that decreasing political support questions seemingly established structures to an extent that may endanger their existence, and in this sense causes unintended consequences that imperil the investments made before to shape these structures. This means that when relatively new but dominant sectors in a region enter into a phase of consolidation and fragility, policy should not yet withdraw, but ought to devise strategies of continuous support. Adaptability and flexibility are crucial in tailoring this support to the specific situation.

While the findings in Oldenburg are in line with the framework suggested in this paper, for a more general assessment, it is necessary to conduct further studies. There is ample need for further research: The investigation of more regions could help to differentiate between particular regional dynamics and general phase-related dynamics. By comparing different regions to each other, inter-regional dynamics could also be considered. Moreover, cross-country comparisons would help to understand better the role of extra-regional context conditions and their interplay with the dynamics in the investigated locations. Finally, a more detailed investigation of the different adaptive strategies that agents apply in the fragile new order may help to develop more appropriate explanations and political responses to said dynamics.

7 References

Agentur für Erneuerbare Energien (2018), "Installierte Leistung Windenergie onshore (2017, in MW)", available at: https://bit.ly/2CVgSCG (accessed 1 August 2019).

Binz, C. and Truffer, B. (2011), "Technological innovation systems in multi-scalar space. Analysing an emerging water recycling industry with social network analysis", *Geographica Helvetica*, Vol. 66 No. 4, pp. 254–260.

Binz, C. and Truffer, B. (2017), "Global Innovation Systems. A conceptual framework for innovation dynamics in transnational contexts", *Research Policy*, Vol. 46 No. 7, pp. 1284–1298.

Binz, C., Truffer, B. and Coenen, L. (2014), "Why space matters in technological innovation systems. Mapping global knowledge dynamics of membrane bioreactor technology", *Research Policy*, Vol. 43 No. 1, pp. 138–155.

Binz, C., Truffer, B., Li, L., Shi, Y. and Lu, Y. (2012), "Conceptualizing leapfrogging with spatially coupled innovation systems: The case of onsite wastewater treatment in China", *Technological Forecasting and Social Change*, Vol. 79 No. 1, pp. 155–171.

Bridge, G., Bouzarovski, S., Bradshaw, M. and Eyre, N. (2013), "Geographies of energy transition: Space, place and the low-carbon economy", *Energy Policy*, Vol. 53, pp. 331–340.

Coenen, L., Benneworth, P. and Truffer, B. (2012), "Toward a spatial perspective on sustainability transitions. Special section on sustainability transitions", *Research Policy*, Vol. 41 No. 6, pp. 968–979.

Coenen, L., Raven, R. and Verbong, G. (2010), "Local niche experimentation in energy transitions: A theoretical and empirical exploration of proximity advantages and disadvantages", *Technology in Society*, Vol. 32 No. 4, pp. 295–302.

Coenen, L. and Truffer, B. (2012), "Places and spaces of sustainability transitions: Geographical contributions to an emerging research and policy field. Introduction", *European Planning Studies*, Vol. 20 No. 3, pp. 367–374.

Cooke, P. (2011), "Transition regions: Regional–national eco-innovation systems and strategies", *Progress in Planning*, Vol. 76 No. 3, pp. 105–146.

Dewald, U. and Truffer, B. (2012), "The Local Sources of Market Formation: Explaining Regional Growth Differentials in German Photovoltaic Markets", *European Planning Studies*, Vol. 20 No. 3, pp. 397–420.

Dijkstra, L. and Poelman, H. (2016), "Regional Definition and Classification", in Richardson, D., Castree, N., Goodchild, M.F., Kobayashi, A., Liu, W. and Marston, R.A. (Eds.), *International Encyclopedia of Geography: People, the Earth, Environment and Technology*, John Wiley & Sons, Ltd, Oxford, UK, pp. 1–13.

Essletzbichler, J. (2012), “Renewable energy technology and path creation: A multi-scalar approach to energy transition in the UK”, *European Planning Studies*, Vol. 20 No. 5, pp. 791–816.

Faller, F. (2016), “A practice approach to study the spatial dimensions of the energy transition”, *Environmental Innovation and Societal Transitions*, Vol. 19, pp. 85–95.

Frangenheim, A., Trippl, M. and Chlebna, C. (2018), “Beyond the ‘single path view’: Inter-path relationships in regional contexts”, *PEGIS - Papers in Economic Geography and Innovation Studies*, No. 2018/06.

Fuenfschilling, L. and Binz, C. (2018), “Global socio-technical regimes”, *Research Policy*, Vol. 47 No. 4, pp. 735–749.

Fuenfschilling, L. and Truffer, B. (2014), “The structuration of socio-technical regimes—Conceptual foundations from institutional theory”, *Research Policy*, Vol. 43 No. 4, pp. 772–791.

Fuenfschilling, L. and Truffer, B. (2016), “The interplay of institutions, actors and technologies in socio-technical systems — An analysis of transformations in the Australian urban water sector”, *Technological Forecasting and Social Change*, Vol. 103, pp. 298–312.

Garud, R., Hardy, C. and Maguire, S. (2007), “Institutional Entrepreneurship as Embedded Agency: An Introduction to the Special Issue”, *Organization Studies*, Vol. 28 No. 7, pp. 957–969.

Garud, R. and Karnøe, P. (2003), “Path Dependence and Creation”, *Administrative Science Quarterly*, Vol. 48 No. 1, p. 154.

Geels, F.W. (2002), “Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study”, *Research Policy*, Vol. 31 No. 8-9, pp. 1257–1274.

Geels, F.W. (2004), “From sectoral systems of innovation to socio-technical systems”, *Research Policy*, Vol. 33 No. 6-7, pp. 897–920.

Geels, F.W., Hekkert, M.P. and Jacobsson, S. (2008), “The dynamics of sustainable innovation journeys”, *Technology Analysis & Strategic Management*, Vol. 20 No. 5, pp. 521–536.

Geels, F.W., Kern, F., Fuchs, G., Hinderer, N., Kungl, G., Mylan, J., Neukirch, M. and Wassermann, S. (2016), “The enactment of socio-technical transition pathways. A reformulated typology and a comparative multi-level analysis of the German and UK low-carbon electricity transitions (1990–2014)”, *Research Policy*, Vol. 45 No. 4, pp. 896–913.

Geels, F.W., Sovacool, B.K., Schwanen, T. and Sorrell, S. (2017), “The Socio-Technical Dynamics of Low-Carbon Transitions”, *Joule*, Vol. 1 No. 3, pp. 463–479.

Gibbs, D. (2018), “Sustainable regions”, in Paasi, A., Harrison, J. and Jones, M. (Eds.), *Handbook on the Geographies of Regions and Territories*, *Research handbooks in geography*, Edward Elgar Publishing, Cheltenham, UK, pp. 182–194.

Grillitsch, M. and Hansen, T. (2018), “Green industrial path development in different types of regions”, *Papers in Innovation Studies*, No. 2018/11.

Grillitsch, M. and Sotarauta, M. (2018), "Regional Growth Paths: From Structure to Agency and Back", *Papers in Innovation Studies*, No. 2018/01.

Hansen, T. and Coenen, L. (2015), "The geography of sustainability transitions. Review, synthesis and reflections on an emergent research field", *Environmental Innovation and Societal Transitions*, Vol. 17, pp. 92–109.

Hodson, M. and Marvin, S. (2012), "Mediating Low-Carbon Urban Transitions? Forms of Organization, Knowledge and Action", *European Planning Studies*, Vol. 20 No. 3, pp. 421–439.

Jedelhauser, M. and Streit, A. von (2018), "Resilienz in regionalen Energietransitionen", in Karidi, M., Schneider, M. and Gutwald, R. (Eds.), *Resilienz: Interdisziplinäre Perspektiven zu Wandel und Transformation*, Springer, Wiesbaden, pp. 267–291.

Klagge, B. and Brocke, T. (2012), "Decentralized electricity generation from renewable sources as a chance for local economic development: a qualitative study of two pioneer regions in Germany", *Energy, Sustainability and Society*, Vol. 2 No. 1, p. 5.

Koehrsen, J. (2017), "Boundary bridging arrangements: A boundary work approach to local energy transitions", *Sustainability*, Vol. 9 No. 3, p. 424.

Koehrsen, J., Mattes, J. and Huber, A. (2019), "Les transitions énergétiques allemandes à l'échelon local: une perspective évolutive des transitions de Bottrop et d'Emden", in Douzou, S., Luck, S. and Guyon, M. (Eds.), *Les territoires de la transition énergétique*, Lavoisier, Paris, pp. 37–54.

Lawrence, T.B. and Suddaby, R. (2006), "Institutions and Institutional Work", in Clegg, S.R. (Ed.), *Handbook of organization studies*, 2. edition, Sage, London, pp. 215–254.

Lee, K. and Malerba, F. (2017), "Catch-up cycles and changes in industrial leadership:Windows of opportunity and responses of firms and countries in the evolution of sectoral systems", *Research Policy*, Vol. 46 No. 2, pp. 338–351.

Mahoney, J. and Thelen, K. (2009), "A theory of gradual institutional change", in Mahoney, J. and Thelen, K. (Eds.), *Explaining institutional change: ambiguity, agency, and power*, Vol. 1, Cambridge University Press, pp. 1–37.

Markard, J. (2018a), "The life cycle of technological innovation systems", *Technological Forecasting and Social Change*.

Markard, J. (2018b), "The next phase of the energy transition and its implications for research and policy", *Nature Energy*, Vol. 3 No. 8, pp. 628–633.

Markard, J., Raven, R. and Truffer, B. (2012), "Sustainability transitions: An emerging field of research and its prospects", *Research Policy*, Vol. 41 No. 6, pp. 955–967.

Martin, R. (2010), "Roepke Lecture in Economic Geography-Rethinking Regional Path Dependence: Beyond Lock-in to Evolution", *Economic Geography*, Vol. 86 No. 1, pp. 1–27.

Mattes, J., Huber, A. and Koehrsen, J. (2015), “Energy transitions in small-scale regions. What we can learn from a regional innovation systems perspective”, *Energy Policy*, Vol. 78, pp. 255–264.

McCauley, S.M. and Stephens, J.C. (2012), “Green energy clusters and socio-technical transitions: analysis of a sustainable energy cluster for regional economic development in Central Massachusetts, USA”, *Sustainability Science*, Vol. 7 No. 2, pp. 213–225.

Ohlhorst, D. (2009), *Windenergie in Deutschland: Konstellationen, Dynamiken und Regulierungspotenziale im Innovationsprozess, Energiepolitik und Klimaschutz,* 1. Aufl., VS Research, Wiesbaden.

Paasi, A., Harrison, J. and Jones, M. (2018), “New consolidated regional geographies”, Introduction, in Paasi, A., Harrison, J. and Jones, M. (Eds.), *Handbook on the Geographies of Regions and Territories*, *Research handbooks in geography*, Edward Elgar Publishing, Cheltenham, UK, pp. 1–20.

Raven, R., Schot, J. and Berkhout, F. (2012), “Space and scale in socio-technical transitions”, *Environmental Innovation and Societal Transitions*, Vol. 4, pp. 63–78.

Rogge, K.S. and Johnstone, P. (2017), “Exploring the role of phase-out policies for low-carbon energy transitions: The case of the German Energiewende”, *Energy Research & Social Science*, Vol. 33, pp. 128–137.

Rotmans, J., Kemp, R. and van Asselt, M. (2001), “More evolution than revolution: transition management in public policy”, *Foresight*, Vol. 3 No. 1, pp. 15–31.

Rotmans, J. and Loorbach, D. (2009), “Complexity and Transition Management”, *Journal of Industrial Ecology*, Vol. 13 No. 2, pp. 184–196.

Schmid, E., Knopf, B. and Pechan, A. (2016), “Putting an energy system transformation into practice: The case of the German Energiewende”, *Energy Research & Social Science*, Vol. 11, pp. 263–275.

Schneidewind, U. and Augenstein, K. (2012), “Analyzing a transition to a sustainability-oriented science system in Germany”, *Environmental Innovation and Societal Transitions*, Vol. 3, pp. 16–28.

Simmie, J. (2012), “Path dependence and new technological path creation in the Danish wind power industry”, *European Planning Studies*, Vol. 20 No. 5, pp. 753–772.

Smith, A. (2007), “Translating Sustainabilities between Green Niches and Socio-Technical Regimes”, *Technology Analysis & Strategic Management*, Vol. 19 No. 4, pp. 427–450.

Sovacool, B.K. (2016), “How long will it take? Conceptualizing the temporal dynamics of energy transitions”, *Energy Research & Social Science*, Vol. 13, pp. 202–215.

Sovacool, B.K., Axsen, J. and Sorrell, S. (2018), “Promoting novelty, rigor, and style in energy social science: Towards codes of practice for appropriate methods and research design”, *Energy Research & Social Science*, Vol. 45, pp. 12–42.

Späth, P. and Rohracher, H. (2010), "'Energy regions': The transformative power of regional discourses on socio-technical futures. Special Section on Innovation and Sustainability Transitions", *Research Policy*, Vol. 39 No. 4, pp. 449–458.

Sperling, K., Hvelplund, F. and Mathiesen, B.V. (2011), "Centralisation and decentralisation in strategic municipal energy planning in Denmark", *Energy Policy*, Vol. 39 No. 3, pp. 1338–1351.

Truffer, B., Murphy, J.T. and Raven, R. (2015), "The geography of sustainability transitions. Contours of an emerging theme", *Environmental Innovation and Societal Transitions*, Vol. 17, pp. 63–72.

Tushman, M.L. and Rosenkopf, L. (1992), "Organizational Determinants of Technological Change. Towards a Sociology of Technological Evolution", *Research in Organizational Behavior*, No. 14, pp. 311–347.

Yin, R.K. (2009), *Case study research: Design and methods, Applied social research methods series*, Vol. 5, 4th ed., Sage, Thousand Oaks, Calif.