Research Policy 45 (2016) 896–913

Contents lists available at ScienceDirect

Research Policy

journal homepage: www.elsevier.com/locate/respol

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)

Frank W. Geels[a,*], Florian Kern[b], Gerhard Fuchs[c], Nele Hinderer[c], Gregor Kungl[c], Josephine Mylan[a], Mario Neukirch[c], Sandra Wassermann[d]

[a] Sustainable Consumption Institute, Manchester Institute of Innovation Research, University of Manchester, Manchester, UK
[b] SPRU, University of Sussex, Brighton, UK
[c] Institute for Social Sciences, University of Stuttgart, Stuttgart, Germany
[d] Center for Interdisciplinary Risk and Innovation Studies, University of Stuttgart, Stuttgart, Germany

ARTICLE INFO

Article history:
Received 26 November 2014
Received in revised form 22 January 2016
Accepted 24 January 2016

Keywords:
Transition pathways typology
Enactment
Low-carbon electricity transition
Multi-level perspective

ABSTRACT

This paper aims to make two contributions to the sustainability transitions literature, in particular the Geels and Schot (2007. Res. Policy 36(3), 399) transition pathways typology. First, it reformulates and differentiates the typology through the lens of endogenous enactment, identifying the main patterns for actors, formal institutions, and technologies. Second, it suggests that transitions may shift between pathways, depending on struggles over technology deployment and institutions. Both contributions are demonstrated with a comparative analysis of unfolding low-carbon electricity transitions in Germany and the UK between 1990–2014. The analysis shows that Germany is on a substitution pathway, enacted by new entrants deploying small-scale renewable electricity technologies (RETs), while the UK is on a transformation pathway, enacted by incumbent actors deploying large-scale RETs. Further analysis shows that the German transition has recently shifted from a 'stretch-and-transform' substitution pathway to a 'fit-and-conform' pathway, because of a fightback from utilities and altered institutions. It also shows that the UK transition moved from moderate to substantial incumbent reorientation, as government policies became stronger. Recent policy changes, however, substantially downscaled UK renewables support, which is likely to shift the transition back to weaker reorientation.

1. Introduction

Early work on socio-technical transitions (Rip and Kemp, 1998; Geels, 2004) emphasized the importance of alignments between developments at multiple levels, characterized in the multi-level perspective (MLP) as niche-innovations, existing regimes and exogenous landscape. Geels and Schot (2007) subsequently suggested that different *kinds* of alignments lead to different transition pathways. They constructed a typology based on combinations between two dimensions: the *timing* and *nature* of multi-level interactions. This led them to distinguish four transition pathways: (1) *technological substitution*, based on disruptive niche-innovations which are sufficiently developed when landscape pressure occurs, (2) *transformation*, in which landscape pressures stimulate incumbent actors to gradually adjust the regime, when niche-innovations are not sufficiently developed, (3) *reconfiguration*, based on symbiotic niche-innovations that are incorporated into the regime and trigger further (architectural) adjustments under landscape pressure, (4) *de-alignment and re-alignment*, in which major landscape pressures destabilize the regime when niche-innovations are insufficiently developed; the prolonged co-existence of niche-innovations is followed by re-creation of a new regime around one of them. Geels and Schot (2007) further proposed that a transition may shift between pathways: "If landscape pressure takes the form of 'disruptive change', a sequence of transition pathways is likely, beginning with transformation, then leading to reconfiguration, and possibly followed by substitution or de-alignment and re-alignment" (p. 413).

While this pathways typology has been useful, it is mainly formulated in processual and phenomenological terms. The typology pays limited explicit attention to agency and institutions. The influence of landscape developments arguably depends not only on timing (compared to niche and regime developments), but also on interpretation and mobilization by actors. Furthermore, whether

* Corresponding author. Tel.: +44 1612757374.
E-mail address: frank.geels@manchester.ac.uk (F.W. Geels).

http://dx.doi.org/10.1016/j.respol.2016.01.015

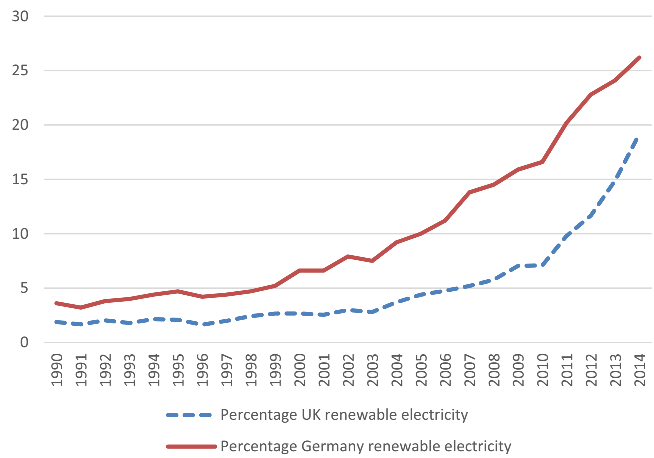

Fig. 1. Percentage of UK and German renewable electricity, 1990–2014 (data from DUKES and AG Energiebilanzen (http://www.ag-energiebilanzen.de/, last accessed June 30, 2015).

niche-innovations are 'symbiotic' or 'disruptive' depends not only on technical characteristics, but also on how such innovations are configured and institutionally embedded. The current pathways typology represents a 'global' (or 'outside-in') conceptual logic, which Poole and Van de Ven (1989: 643) characterize as depicting "the overall course of development of an innovation" which "takes as its unit of analysis the overall trajectories, paths, phases, or stages in the development of an innovation". They contrast this with a 'local' (or 'inside-out') conceptual logic which depicts "the immediate action processes that create short-run developmental patterns" and focuses on "the micro ideas, decisions, actions or events of particular developmental episodes". Building on their suggestion that process theories should ideally have both logics, the paper's first aim is to develop the 'local' logic of the transition pathways typology. So, we aim to reformulate and differentiate the existing transition pathways in terms of endogenous enactment, using the conceptual categories from Geels (2004), who distinguished between: (1) actors and social groups, (2) rules and institutions, and (3) technologies and wider socio-technical system. Our reformulation strategy, first, brings together and systematizes insights from other transition papers and, second, imports some ideas from other literatures. The second aim is to develop alternative understandings of shifts between transition pathways, which depend less on external landscape pressure and more on shifting actor coalitions, struggles, and adjustments in formal rules and institutions.

To demonstrate our contributions, we present a comparative analysis of the unfolding low-carbon electricity transitions in the UK and Germany. Both countries have developed ambitious electricity transition plans. Following the 2011 Fukushima nuclear accident, the German government adopted an official energy transition strategy, the *Energiewende*, which included a nuclear phase-out by 2022 and renewable electricity goals of 35% by 2020, 40–45% by 2025, 55–60% by 2035 and 80% by 2050. The 2008 UK Climate Change Act committed to 80% reduction of greenhouse gas (GHG) emissions by 2050. The UK Low Carbon Transition Plan (2009) articulated a target of 30% renewable electricity by 2020 and almost complete decarbonisation of electricity by 2030. Both countries have made some progress, with the contribution of renewables to power generation increasing between 1990 and 2014 from 3.6% to 26.2% in Germany and from 1.9% to 19.1% in the UK (Fig. 1).

We will show that both countries followed very different transition pathways, with Germany enacting a technological substitution pathway (which we characterize as 'unleashing new entrants') and the UK a transformation pathway (which we characterize as 'working with incumbents'). Analysing actors, institutions, and deployed technologies, we also show how struggles and conflicts led to shifts between transition pathways in both countries.

Section 2 describes our conceptual reformulations and differentiations of the transition pathways typology. Section 3 discusses case-selection and data sources. Sections 4 and 5 present analyses of the UK and German electricity transitions. Section 6 discusses findings. Section 7 offers conclusions.

2. Conceptual perspective

2.1. Background assumptions

Before reformulating the transition pathways typology (Section 2.2), we briefly explicate our assumptions about agency and indicate how a 'local' (enactment) logic can be related to the 'global' MLP logic (of trajectories and alignments). This is also important because some scholars have (incorrectly in our view) claimed that the MLP does not accommodate agency, conflict and struggle. Drawing on insights from science and technology studies (STS), evolutionary economics and neo-institutional theory, Geels (2004) distinguished between: (1) actors and social groups, (2) rules and institutions, (3) technologies and socio-technical system, and articulated dynamic interactions. He used the metaphor of socially embedded 'game playing' to emphasize the moves and countermoves of actors and social groups, which are constrained by 'rules of the game' and oriented towards reproducing or modifying elements of socio-technical systems. "In each round actors make 'moves', i.e. they do something, e.g. make investment decisions about R&D directions, introduce new technologies in the market, develop new regulations, propose new scientific hypotheses. These actions maintain or change aspects of ST-systems. The dynamic is game-like because actors react to each other's moves" (Geels, 2004: 909). These games include interpretations and power: "Different actors do not have equal power or strength. They have unequal resources (e.g. money, knowledge, tools) and opportunities to realize their purposes and interest, and influence social rules. The framework leaves room for conflict and power struggles. After all, there is something at stake in the games" (p. 909).

Geels and Schot (2010) further elaborated these notions and articulated the link between agency and field-level trajectories. They suggested that a trajectory can be conceptualized as a sequence of events (or 'event chain') and that each event can be analysed in terms of more specific 'morphogenetic cycles' (Archer, 1982), constituted by four successive mechanisms (Fig. 2): (1) structural conditioning of actors by existing rules and institutions, (2) social interaction between actors (search, learning, collaboration, sense-making, conflict, moves, countermoves), (3) structural elaboration (reproduction of rules and institutions or efforts to modify them via institutional entrepreneurship), and (4) externalization and institutionalization (acceptance and retention of rule changes). This conceptualization means that trajectories in the MLP are always enacted and that even stable trajectories require continuous effort by actors (via reproduction).

This basic conceptualisation of the enactment of trajectories informs our reformulation of transition pathways below, which vary in terms of who the dominant actors are and how they shape the reproduction or change of rules and institutions. This

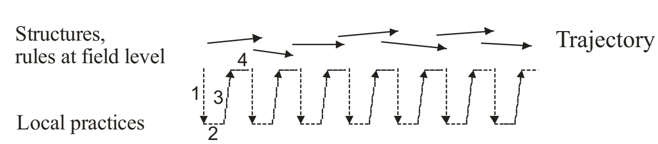

Fig. 2. Trajectory as field-level event chain, resulting from successive morphogenetic cycles (Geels and Schot, 2010: 52).

basic conceptualisation also means that transitions can be analysed with lenses of different granularity (Geels and Schot, 2010): (1) aggregate explanations in terms of alignments of trajectories within and between niche, regime and landscape levels, (2) explanations of trajectories in terms of event-chains and rounds of moves and counter-moves, (3) explanations of particular events or local projects by zooming in on specific actors and (local) contexts.

The current pathways logic, discussed in Section 1, is mainly formulated through the first lens. Below we try to reformulate different transition pathways through the second lens, focusing on the interactions between actors, rules and institutions and technologies, and how these result in different kinds of trajectories. The third lens has received attention in the strategic niche management literature (Hoogma et al., 2002), but may be less useful for the conceptualisation of transition *pathways* which refer to more aggregate patterns over longer time periods.

2.2. Reformulating and differentiating transition pathways

This section reformulates and differentiates the four transition pathways from Geels and Schot (2007) in terms of actors, technologies and institutions. We thus make two simplifications compared to Geels (2004). First, while the analytical style remains socio-technical, the empirical focus is on technologies rather than broader systems. This focus stems from the case demarcation, which is about electricity *generation* rather than the entire electricity system (which would also include the grid and electricity use). Second, we focus primarily on *formal* rules and institutions rather than normative and cultural-cognitive institutions. This simplification enables us to mobilize ideas from neo-institutional political science with regard to changes in formal rules and institutions. But it also means that interpretive and discursive dimensions receive somewhat less attention, which thus forms a limitation of our reformulations.

Thelen (2003) characterized most of the institutional literature in political science as following a punctuated equilibrium view, in which institutions either develop through *incremental adjustments* (based on policy learning) or are *disrupted* by external shocks, followed by rapid substitution of new institutions. She additionally proposed four other mechanisms that go beyond this dichotomy: *layering*, in which new institutions are layered on top of existing arrangements without affecting their core logic; *drift*, in which on-the-ground implementation gradually changes policies-in-use without any official decision; *conversion*, in which the goals of existing policies are adjusted, while instruments remain unchanged; *displacement*, in which new institutions slowly overtake existing ones. Mahoney and Thelen (2010) further suggested that 'layering' and 'drift' stay closer to existing institutions, while 'displacement' and 'conversion' represent more significant change. They also suggested that institutional changes often entail conflicts between incumbents, subversives and other actors, which may involve veto power, coalition building, and other means of blocking or facilitating change. So, combined with the earlier mechanisms (incremental adjustment, disruption), we suggest that the neo-institutional literature offers several change mechanisms that can be usefully applied in a reconceptulisation of the four transition pathways (see also Dolata, 2013). For the first two pathways, we aim at reformulation and differentiation, based on particular combinations of change mechanisms for actors, technologies and institutions. For the last two pathways, our contributions remain limited to reformulation.

2.2.1. Substitution pathway

In the original formulation of the substitution pathway, niche and regime technologies initially develop separately (because radical niche-innovations are shielded by supportive policies) and are carried by different actors (new entrants and incumbents). The actual overthrow involves direct struggles between technologies and associated actors, often in the context of broader landscape changes that affect the selection criteria and institutions in mainstream markets.

We propose further differentiations in the enactment of the substitution pathway with regard to 'actors' and 'institutions'. With regard to actors, the 'normal' Schumpeterian pattern is that *new firms* struggle against established firms. Socio-technical transition scholars, however, have found that radical sustainability innovations may also be developed and deployed by outsiders such as activists, social movements and citizens with normative motivations (Seyfang and Smith, 2007). New entry may also come from incumbents that diversify from other sectors, e.g. Internet companies moving into renewable energy or driverless cars.

With regard to institutions, the substitution pathway may follow two patterns. The first pattern occurs with limited institutional change [*incremental adjustment; layering*], when innovations with better price/performance characteristics disrupt existing technologies. Smith and Raven (2012) call this a 'fit-and-conform' pattern, in which niche-innovations are developed to fit existing rules and institutions. In the second pattern, which Smith and Raven (2012) call 'stretch-and-transform', rules and institutions are adjusted to suit the niche-innovation [*disruption; displacement*]. These institutional changes are likely to involve power struggles, socio-political mobilization and counter-mobilization (Schneiberg and Lounsbury, 2008; Geels, 2014a).

2.2.2. Transformation pathway

The transformation pathway consists of gradual reorientation of the existing regime through adjustments by incumbent actors in the context of landscape pressure, societal debates and tightening institutions. We propose further differentiations with regard to actors, technologies and institutions.

While Geels and Schot (2007) emphasized adjustments through *incremental* changes in search routines and technology, we propose that incumbent actors may also reorient towards *radical* niche-innovations. So, incumbent actors do not necessarily remain 'locked in' to the existing regime, as is commonly assumed in the MLP. Instead, they can change strategic direction and reorient themselves, as the strategy literature has suggested with notions such as 'exploration-exploitation' (March, 1991) and 'ambidextrous organization'. We thus go beyond the established dichotomy that incumbents do incremental innovation and new entrants do radical innovations (see also Bergek et al., 2013; Berggren et al., 2015). We further suggest that incumbent reorientation can have different 'depths', depending on the kinds of organizational elements that are adjusted (Geels, 2014b): (a) search routines and standard-operating procedures, (b) technical capabilities and economic positioning strategy, (c) beliefs, identity, mission, business model. The 'deeper' organizational elements are more difficult to change, entailing different kinds of processes and causal mechanisms (Fig. 3).

With regard to technologies, our differentiation not only includes incremental change in the *existing* technology, but also two other options: (1) competence additions (Geels, 2006) or 'creative accumulation' (Bergek et al., 2013), which refers to the integration of new knowledge within existing regimes, (2) reorientation towards new technologies (with or without changes in deeper beliefs and identities)[1]. This reorientation process often proceeds gradually, first through defensive hedging, then diversification, then full reorientation (Geels, 2014b; Geels and Penna, 2015).

[1] This second option has a similarity with the technical substitution pathway, because both involve a shift from old to new technologies. They differ, however, in terms of enactment.

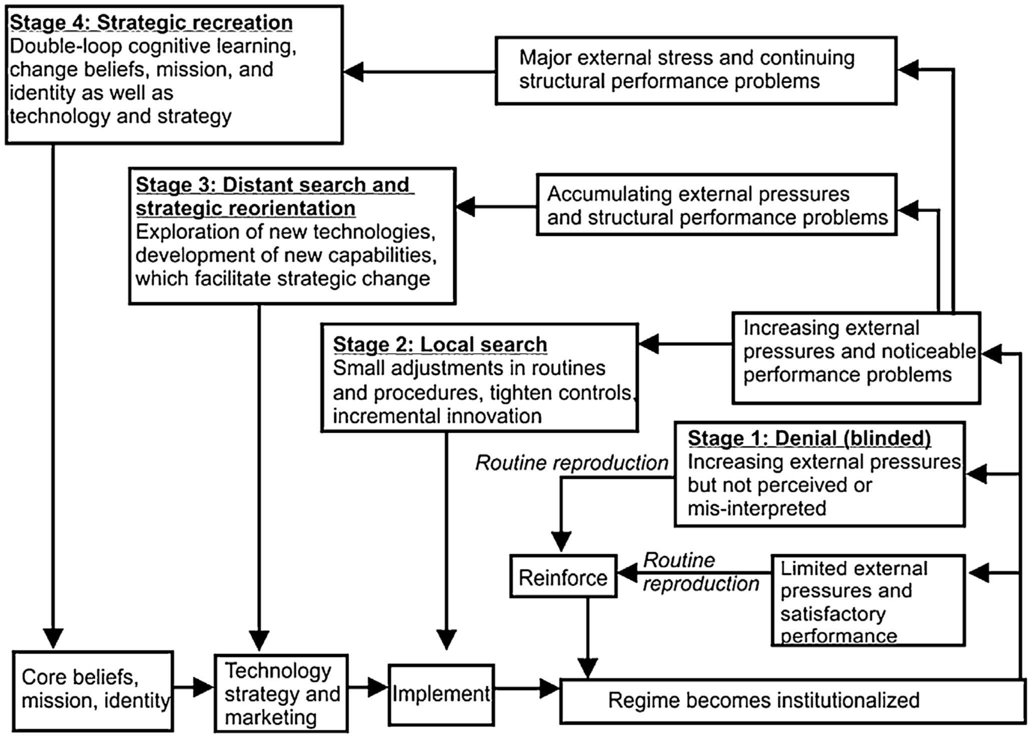

Fig. 3. Dynamics of strategic reorientation (Geels, 2014b: 272).

The speed and degree of reorientation depends on the strength of socio-political pressures and perceived market opportunities.

With regard to institutions, we suggest that different depths of reorientation are associated with different degrees of institutional change (Geels and Penna, 2015). Incremental technical change and add-ons are likely to involve limited institutional change ('layering'). Partial reorientation (based on technical diversification) and full reorientation (based additionally on changing beliefs and mission) entail higher degrees of institutional change ('conversion', 'displacement'), which enhance pressure on incumbents. Different degrees of institutional pressure in the transformation pathway are likely to involve struggles between policymakers and industry actors (Smink et al., 2015).

2.2.3. Reconfiguration pathway

In the reconfiguration pathway, niche-innovations and the existing regime combine to transform the system's architecture. We propose some minor reformulations, rather than differentiations. In terms of actors, this pathway can involve *new alliances* between incumbents and new entrants rather than overthrow (Rothaermel, 2001)[2].

In terms of technologies, niche-innovations may initially be incorporated as 'modular innovation' (Henderson and Clark, 1990) or as 'add-on' to existing technologies (which thus has similarities to the 'transformation' pathway). Subsequently, however, these new technologies may create unintended problems or opportunities that invite further changes, thus triggering 'innovation cascades' (Berkers and Geels, 2011) that substantially reconfigure system components and their relations. Knock-on effects, 'new combinations' between multiple innovations, second-order learning processes (which change beliefs and goals), and unintended consequences give this transition pathway an open-ended character.

Reconfiguration processes are likely to start with limited institutional change ('layering'), followed by more substantial change ('drift', 'conversion') as actors encounter new problems, change their goals and see new opportunities. Institutional change may involve *struggles* between new entrants and incumbents to suit their interests.

2.2.4. De-alignment and re-alignment pathway

In the de-alignment and re-alignment pathway, the existing regime is disrupted by external shocks, which is followed by the rise of multiple niche-innovations and constituencies, one of which gradually becomes dominant. This pathway has not been investigated much, so we only propose some reformulations with regard to actors, technologies and institutions.

New entrants and incumbents do not engage in a head-on confrontation, but are temporally separated: incumbent actors lose faith in the regime's viability (because of major shocks) before being challenged by new entrants. The core process of regime destabilisation has not been investigated much (see Turnheim and Geels, 2013, for an exception). More generally, transitions research has not yet paid much attention to the role of really large shocks (e.g. wars, population displacements, economic collapse), despite the suggestion by Freeman and Perez (1988) that major paradigm shifts often involve societal crises.

The destabilisation and decline of the existing technology creates space for the emergence of (several) radical niche-innovations, which compete more with each other than with the 'old' technology.

In terms of institutions, the existing (punctuated equilibrium) literature (Meyer, 1982) suggests that when environmental jolts disrupt existing institutions, actors engage in search, learning and struggles to establish new institutions. Extremely large shocks, however, may create prolonged uncertainty because the absence of institutional templates hinders adaptation and learning:

[2] These alliances often entail conflicts because of power differentials and conflicting interests.

Table 1
Reformulated and differentiated transition pathways.

Transition pathway	Actors	Technologies	Rules and institutions
(1) Substitution	New firms struggle against incumbent firms, leading to overthrow	Radical innovation(s) substituting existing technology	Limited institutional change, implying that niche-innovation needs to compete in existing selection environment ('fit-and-conform') ('Incremental adjustment', 'Layering')
	Different kinds of 'new entrants' (e.g. citizens, communities, social movement actors, incumbents from different sectors) replace incumbents		Creation of new rules and institutions to suit the niche-innovation ('stretch-and-transform') ('Disruption', 'Displacement')
(2) Transformation	Incumbents reorient incrementally by adjusting search routines and procedures	Incremental improvement in existing technologies (leading to major performance enhancement over long time period).	Limited institutional change ('Layering')
		Incorporation of symbiotic niche-innovations and add-ons (competence-adding, creative accumulation)	
	Incumbents reorient substantially, to radically new technology or, even more deeply, to new beliefs, mission, and business model	Reorientation towards new technologies: (a) partial reorientation (diversification) with incumbents developing both old and new technologies (b) full reorientation, leading to technical substitution	Substantial change in institutions ('Conversion', 'Displacement')
(3) Reconfiguration	New alliances between incumbents and new entrants	From initial add-ons to new combinations between new and existing technologies; knock-on effects and innovation cascades that change system architecture.	From limited institutional change ('Layering') to more substantial change, including operational principles ('Drift', 'Conversion')
(4) De-alignment and re-alignment	Incumbents collapse because of landscape pressure, creating opportunities for new entrants	Decline of old technologies creates space for several innovations which compete with one another	Institutions are disrupted by shocks and replaced, possibly after prolonged uncertainty ('Disruption')

> when institution-level change is too extreme, when the underlying values, ideologies and norms in society are in question, and when the economic and political systems are in disarray, it is difficult for managers to coalesce around a new set of value commitments and almost impossible to find the 'right' new organizing template (Newman, 2000: 605)[3].

During the institutional 'vacuum', multiple groups and constituencies are likely to struggle over the shape of new institutions. Stability returns when one group (or coalition) prevails.

Table 1 summarizes the reformulated and differentiated transition pathways along the three categories (actors, technologies, institutions). These reformulated pathways go beyond traditional dichotomies and provide a more nuanced analytical apparatus to analyse unfolding transition processes.

2.3. Shifts between pathways

Our reconceptualisation also enables a more fluid understanding of shifts *between* pathways as transitions unfold, which depends less on external landscape change, as in Geels and Schot (2007), and more on endogenous enactment. The general starting point is that transitions are not teleological and deterministic, but continuously enacted by and contested between a variety of actors. Both technology deployment and institutions are continuous sites of struggle (Smith and Raven, 2012), as actors argue for or against the effectiveness, costs and desirability of certain technologies, policy goals and policy instruments. So, transitions are likely to be non-linear; two steps forward may be followed by one step back (or steps in a different direction if actors change their beliefs and goals or if there is growing contestation of particular pathways). This idea has been confirmed in earlier work on major change processes. With regard to the transition towards welfare states, for instance, Meadowcroft (2005: 15) found that "periods of rapid growth or innovation alternated with phases of consolidation or stagnation. The development of the welfare state was not smooth, but uneven and episodic." Organization scholars similarly found that social movements create new paths through several *rounds* of protests: "Central to field and path creation is some sort of collective mobilization or movement, not just a single burst of organization, but also waves or cycles of mobilization and organizational formation" (Schneiberg and Lounsbury, 2008: 664). Non-linearities also arise from active delay and resistance strategies from incumbents (Geels, 2014a; Smink et al., 2015), including the creation of counter-movements.

Our specific contribution is the suggestion that non-linearities may also take the form of shifts *between* transition pathways as struggles between actors affect technology deployment and institutions. Building on Section 2.2, we distinguish several instances of such shifts, illustrated with examples:

- Transitions may start along the transformation pathway via a technical add-on, and subsequently morph into a reconfiguration pathway as the new technology has wider knock-on effects that trigger innovation cascades and learning processes that change actors views, leading them also to lobby for institutional change. Berkers and Geels (2011), for instance, showed how the architecture and practice of Dutch horticulture was transformed between

[3] Newman (2000) suggests that the fall of communism created so many uncertainties that organizations were still in flux ten years later.

1960 and 1980 because of successive add-ons, learning processes and new combinations (e.g. gas-fired heating, artificial lighting, artificial watering systems, new vegetable breeds, CO_2 fertilization, new kinds of glass panels).

- A transition may start as a 'fit-and-conform' substitution pathway, but gradually morph into a 'stretch-and-transform' pathway as the coalition of niche-actors becomes stronger and is able to lobby for new institutions that create more favourable conditions. An example of this pattern is the development of offshore wind in the UK (Kern et al., 2014a) The opposite is also possible, with a transition changing from a 'stretch-and-transform' to a 'fit-and-conform' substitution pathway; this may happen when fight-back from incumbent actors leads to weaker rules that require niche-innovations to fit into existing structures. We will suggest that the German electricity transition is currently experiencing this shift between pathways.
- A transition may change from a substitution pathway to a reconfiguration pathway if incumbent actors are able to change the institutions so that they offer support for continued existence of regime technologies besides niche-innovations. We will suggest that recent German policies, particularly capacity markets, open the prospect of this shift, as they enable coal to continue besides renewables.
- A transition may start as an incremental transformation pathway, based on limited institutional pressure ('layering'), but subsequently morph into a more substantial reorientation pathway if increasing institutional pressure incentivises incumbent firms to diversify or switch towards new technologies. We will suggest that the UK electricity transition has followed this pattern as low-carbon policies became stronger (especially between 2008 and 2014). The speed and depth of different variants of the transformation pathway depends on the strength of policy pressure. Fightback and resistance from incumbents may weaken policy pressure and stifle the reorientation, which seems to have happened very recently (July, 2015) in the UK case.
- A transition may start as a substitution pathway, in which new entrants challenge incumbent firms, but subsequently morph into a transformation pathway if incumbents buy up the small firms to control the radical innovation. This pattern happened to some degree in the 1990s when big car companies bought up small electric vehicle firms, like Th!nk (Hoogma et al., 2002).

Actor struggles and shifts between transition pathways are influenced by a range of developments: changing composition and strength of actor coalitions; learning processes and on-the-ground experiences (e.g. technology deployment going faster or slower than expected, deployment costs higher or lower than anticipated); landscape developments (e.g. elections, accidents, macro-economic trends, commodity price developments).

More generally, actor struggles and the likelihood of transition pathways, and shifts between them, are also affected by *static* landscape characteristics, which provide affordance structures and action possibilities (Geels and Schot, 2010) that shape but do not determine action. These *static* landscape structures were mentioned in Van Driel and Schot (2005), but have generally been overlooked in transition research, which tends to focus on landscape *changes*. Especially for comparative research, however, this category is useful to acknowledge deep-structural differences between countries in terms of constitutional structures, policy styles, ideologies, and economic structures[4]. So, even when the same kinds of actors are involved, we should expect different enactment patterns between countries because static landscape structures create different affordances and action possibilities.

3. Case selection and data sources

The paper employs a comparative case study methodology, investigating unfolding electricity transitions in Germany and the UK. Both transitions will be investigated as longitudinal case studies (starting in 1990), because transitions are long-term processes and because the formal transition plans emerged out of preceding developments, struggles, setbacks, mobilizations and opportunities. We selected these countries because they see themselves as frontrunners in the low-carbon electricity transition, but have very different profiles. Although similar renewable electricity technologies (RETs) were available in both countries, variations in actors and institutions led to substantial differences in patterns of RET-deployment (Figs. 4 and 5). These countries thus form good cases to test our reformulated and differentiated transition pathways.

Many RETs are scalar technologies and can be deployed in different configurations. Figs. 4 and 5 show that Germany mainly deployed small-scale decentralized RETs (onshore wind, solar-PV, biogas), while the UK mainly deployed large-scale centralized RETs (onshore wind farms, offshore wind farms, biomass conversion of coal power stations, landfill gas)[5]. The UK also considers two other large-scale low-carbon options (nuclear power, Carbon Capture and Storage) as key to its electricity transition. These options are not seen as part of the German low-carbon transition.

The case studies use quantitative energy statistics and qualitative information about motivations, social interactions, events, and struggles from secondary sources (academic books, articles, committee reports), complemented with primary sources (government reports, newspapers). The analysis aims to synthesize these data into a comprehensive interpretation. The process tracing of event chains is fairly aggregate, because we cover many developments over a long period. We aim to address the first two layers of granularity, mentioned in Section 2.1, and don't zoom in to the level of specific events, actors or decisions.

Both longitudinal cases are divided into periods: 1990–1998, 1998–2009, 2009–2014 for Germany, and 1990–2002, 2002–2008, 2008–2014 for the UK. This demarcation is roughly based on acceleration points in the renewable expansion curves (Fig. 1) and on major institutional changes. For each period, we discus 'actors and institutions' and 'actors and technologies' for the regime and for renewable niche-innovations that have seen some deployment.

4. The German low-carbon electricity transition

4.1. Nurturing niches in the context of stable and hostile regimes (1990–1998)

4.1.1. Regime dynamics

4.1.1.1. Actors and institutions. The German electricity market was constituted as a 'natural monopoly', with nine vertically integrated public utilities providing electricity within demarcated territories under tight regulatory supervision (Bontrup and Marquardt, 2011). These nine companies formed the backbone of the German electricity regime. Eighty regional supply companies and about nine hundred municipal utilities guaranteed electricity distribution at regional and local level.

[4] This idea also accommodates Marx's aphorism that 'men make their own history, but not in conditions of their own choosing'.

[5] Onshore wind can be implemented as large-scale wind farms (many dozens of turbines operated by project developers or utilities) or in smaller numbers (1–15 turbines operated by citizens, farmers or cooperatives). The former option is more prevalent in the UK, and the latter in Germany where 68% of wind parks are smaller than 10 MW (data from Bundesnetzagentur).

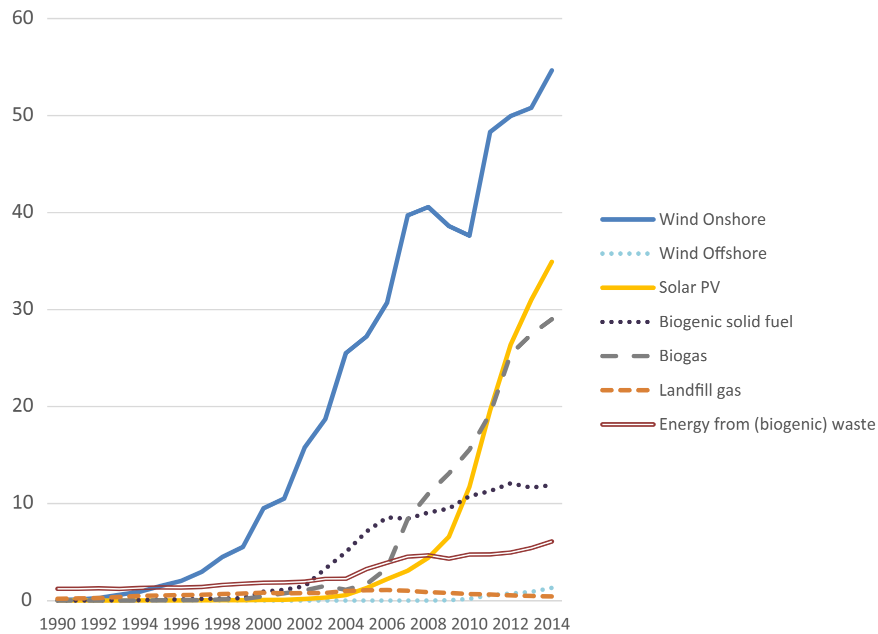

Fig. 4. Power production from German renewable energy technologies, excluding hydro, in TW h, 1990–2014 (from: http://www.erneuerbare-energien.de/EE/Navigation/DE/Service/Erneuerbare_Energien_in_Zahlen/Zeitreihen/zeitreihen.html).

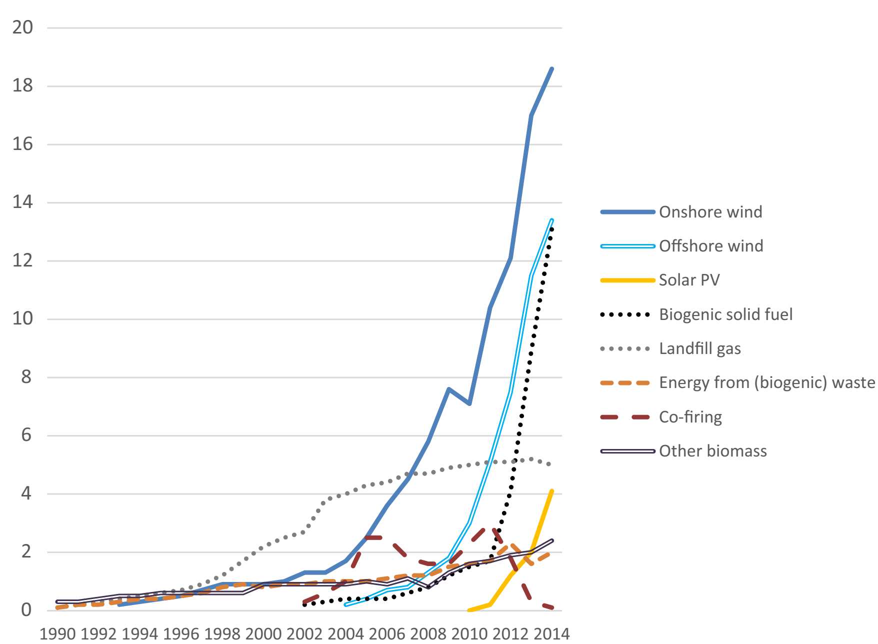

Fig. 5. Power production from UK renewable energy technologies, excluding hydro, in TW h, 1990–2014 (data from DUKES: Digest of UK Energy Statistics, https://www.gov.uk/government/collections/digest-of-uk-energy-statistics-dukes)[16].

4.1.1.2. Actors and technologies. Power generation in the 1990s relied on fossil fuels and nuclear power, complemented with some hydro-power and oil (Fig. 6).

German hard ***coal*** production was traditionally perceived as a national asset and received subsidies since the 1960s. Nevertheless, the number of mines declined from 146 in 1960 to 39 in 1990 to 12 in 2000, and (intended) full closure in 2018. Hard coal for electricity generation was strongly supported, with subsidies growing from 0.4 billion euro in 1975 to more than 4 billion euro in the early 1990s (Jacobsson and Lauber, 2006). Cheaper brown coal (lignite) generally remained competitive, although many former East German mines were closed after re-unification, which decreased production from 356.5 million tons in 1990 to 192.7 million tons in 1995 (www.kohlestatistik.de.).

Nuclear power faced substantial opposition from the anti-nuclear movement, which halted new nuclear construction in the 1980s. The Chernobyl accident (1986) hardened negative public attitudes, with opposition parties (Greens, Social Democrats) favouring closure. But the Conservative-Liberal government, along with the big utilities, supported nuclear power in the 1990s.

4.1.2. Renewable niche-innovations

4.1.2.1. Actors and institutions. Small wind turbines were already deployed in the late 1980s by farmers, environmentally motivated citizen groups and smaller utilities (Neukirch, 2010). They

[16] 'Other biomass' includes biogas, sewage sludge, and animal biomass.

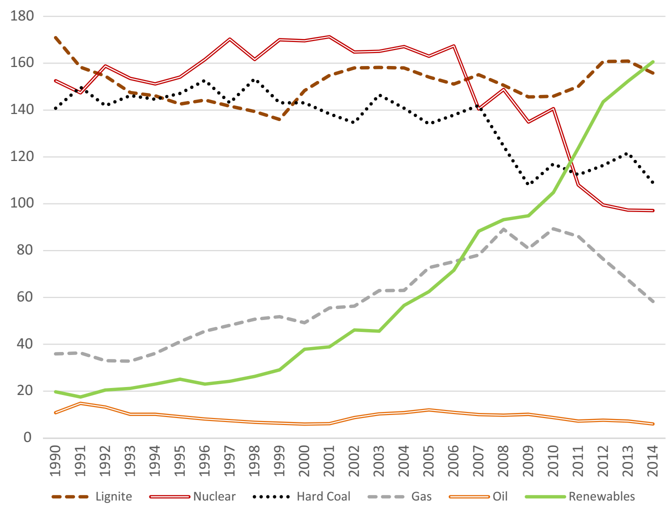

Fig. 6. German electricity generation by fuel type, 1990–2014, in TW h (from: AG Energiebilanzen e.V. as of June, 6th 2014 http://www.ag-energiebilanzen.de/ (last accessed July, 29th 2014).

benefitted from positive public perceptions, general interest in energy topics, and strong anti-nuclear sentiments (Mautz et al., 2008). Public campaigns led members of Parliament to propose RET market support laws in 1987, 1988 and 1989 (Byzio et al., 2002). These proposals were opposed by the Economics Ministry and rejected by the CDU/FDP government, which generally disliked RETs (Jacobsson and Lauber, 2006). In 1990, a new proposal succeed 'by accident' (Lauber and Jacobsson, 2016), as the government was more concerned with German re-unification. It was also not expecting the Feed-In-Law to have major effects, anticipating originally only a few hundred MW of hydropower (Jacobsson and Lauber, 2006). In 1994, even the Minister of Environmental Affairs (Angela Merkel) thought it unlikely that Germany would ever generate more than 4% renewable electricity (Lauber and Jacobsson, 2016).

The 1990 Feed-In-Law obliged utilities to connect RETs to the grid and to buy renewable electricity at a percentage of the household price of electricity. It also excluded installations in which a public utility held shares of more than 25%. Although the big utilities had little interest in deploying new RETs (which conflicted with their business models), they did deploy resistance tactics. First, they contested the legality of the Feed-In-Law in German courts in 1995 and with an appeal to the European Court of Justice in 1998 (Tacke, 2004). This contestation created regulatory uncertainty, until the European Court ruled against the plaintiffs in 2001. Second, utilities tried to delegitimize renewable electricity, claiming that wind energy was expensive and unreliable (Tacke, 2004). Utility pressure led to a government proposal in 1997 for a reduction of feed-in tariffs, which gave rise to a large protest demonstration by environmental, solar and wind associations, as well as metal workers, farmer groups and church groups. The proposal was subsequently rejected in Parliament (Jacobsson and Lauber, 2006).

4.1.2.2. Actors and technologies. The Feed-In-Tariff (FiT) made onshore ***wind*** deployment economically feasible (Byzio et al., 2002) and stimulated deployment in the 1990s (Fig. 4), often by citizen groups and anti-nuclear activists (Byzio et al., 2002). The economic success of German turbine builders (Enercon, Husumer Schiffswerft, Tacke) also expanded the support coalition (Neukirch, 2010) and attracted industrial policy support in peripheral regions of Northern Germany.

Solar-PV remained small, because the FiT was too low to make it economically viable. Nevertheless, public views of solar-PV were very positive. The government therefore introduced a 1000 PV roof programme, which attracted much interest and was soon oversubscribed. Despite installation of 5.3 MW by 1993 (Jacobsson and Lauber, 2006), policy support was not extended. Big solar-PV producers like Siemens therefore left Germany in the mid-1990s, and other firms threatened to follow suit. Green NGOs and industrial firms subsequently lobbied for an ecological modernization strategy in which Germany would become a first-mover to develop a solar-PV industry (Fuchs and Wassermann, 2008).

Although the FiT was too low to create a market for ***biogas***, ecologically motivated farmers like the 'Bundschuh-Biogasgruppe' built their own biogas plants, based on anaerobic waste digestion (Mautz et al., 2008). They also created the German Biogas Association, which lobbied successfully for some FiT-increase in 1998.

4.2. Parallel expansion of regime and niches (1998–2009)

4.2.1. Regime dynamics

4.2.1.1. Actors and institutions. The liberalization of the German electricity sector in 1998 led utilities to focus on economic expansion through mergers and acquisitions. Market consolidation resulted in the 'Big-4′ (RWE, E.ON, Vattenfall, EnBW), which by 2004 generated 90% of all power. The 'Big-4′ also acquired shares in regional suppliers and municipal utilities (Bontrup and Marquardt, 2011), but this strategy eventually faced restrictions from antitrust law. Utilities therefore also expanded at the European and global level (Kungl, 2015). Stock prices of big German utilities increased substantially until 2008 (Fig. 7). The formation of a Red-Green government (1998–2005) was a substantial shock for regime actors, because of radically new policies on nuclear power (phase-out) and renewables (support).

Liberalization also affected municipal and regional utilities, which searched for new roles after the 1998 market opening, leading to diversification. Some remained regime actors (focused on electricity distribution); some were taken over by the big utilities; others strived for independence, moved into power generation, and thus became new entrants, often with an RET-orientation (Bontrup and Marquardt, 2011; Berlo and Wagner, 2013).

4.2.1.2. Actors and technology. The utilities concentrated on large-scale coal- and gas-fired power plants. By the mid-2000s, they built many new ***coal***-fired plants (Pahle, 2010). Coal-mining subsidies declined from 4.45 billion euros in 2000 to 2.5 billion in 2013 (cp. 13 Subventionsbericht der Bundesregierung), but still represented substantial state support. The 2005 European Emissions Trading Scheme created some concern about emissions from coal-fired power in the long run, which stimulated utilities to embark on (government co-sponsored) R&D programs into carbon capture and storage.

Nuclear power faced substantial pressure, because the newly elected Red-Green government introduced the amended Atomic Energy Law (2002), which specified a gradual nuclear phase-out (limiting lifetimes of nuclear plants to 32 years since construction). When the Red-Green coalition ended in 2005, the utilities lobbied to reverse this phase-out decision. They intensified their campaign when a new center-right government took power (2009), lobbying policymakers and trying to shape public perceptions through annual reports, newspaper interviews and public relations activities which emphasized the safety of nuclear power, its low-carbon credentials, and its contributions to energy security (Kungl, 2015).

4.2.2. Renewable niche-innovations

4.2.2.1. Actors and institutions. In 2000, the Red-Green government published a climate protection programme that aimed for 25% CO_2-reduction by 2005, compared to 1990, and 10% renewable electricity in 2010. In 2002, the renewable electricity target

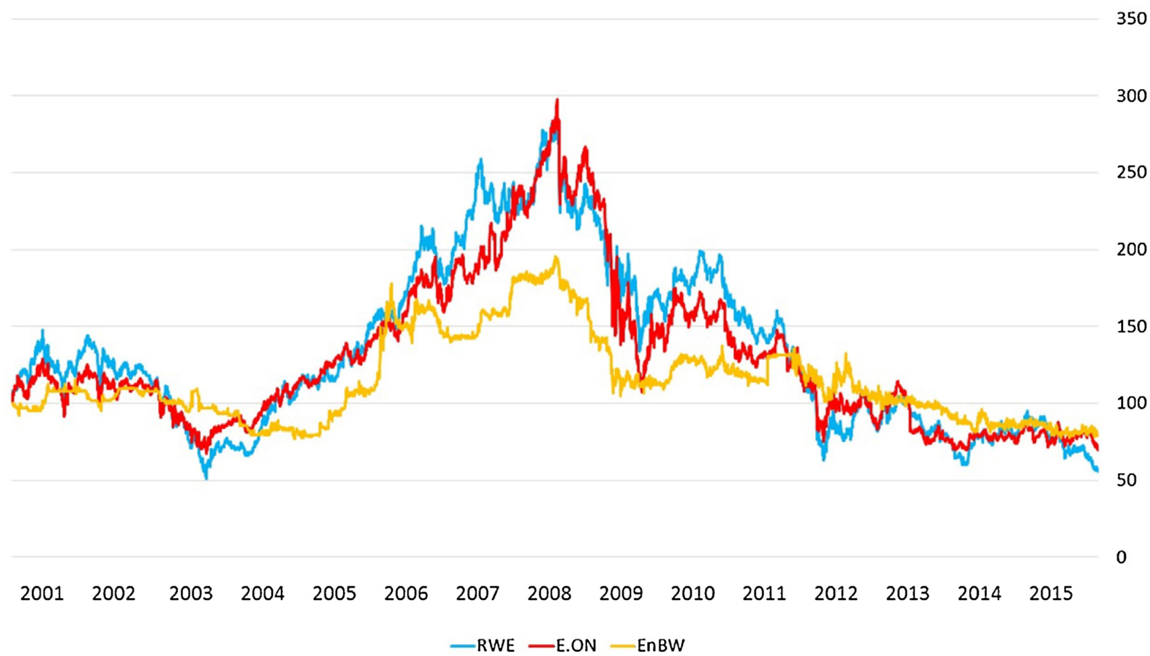

Fig. 7. Normalized stock price performance of three German utilities (Frankfurt stock exchange www.finanzen.net, accessed on February 3, 2014).

was increased to 12.5% by 2010 and 60% in 2050 (Jacobsson and Lauber, 2006). To achieve these targets, the government introduced the Renewable Energy Sources Act (EEG), which obliged grid operators to connect RET-facilities with priority, guaranteed consistent minimum payment for renewable electricity for 20 years, and adjusted financial support levels to the maturity of different technologies. The EEG was supported by a broad advocacy coalition, which included environmentally-oriented organisations (Eurosolar, Förderverein Solarenergie, Greenpeace, PV-companies), as well as organisations from metal and machine-building sectors (Jacobsson and Lauber, 2006).

Another important rule change was the transfer, in 2002, of responsibility for renewable energy from the Ministry of Economic Affairs, which had negative orientations towards RETs, towards the Ministry for Environmental Affairs.

The EEG protected renewable electricity and stimulated substantial expansion (Fig. 1), which created economic pressure on utilities. Utilities tried to discredit the EEG by criticizing regulations that in their opinion derailed market mechanisms and raised costs. E.ON's CEO, for instance, stated that: "There is no use for us being a pioneer in climate protection if we thereby weaken our position in international competition. 300 jobs disappear every day. We cannot afford eco-policy at any price" (WirtschaftsWoche, May 6, 2004).

In subsequent years, the EEG evolved through larger changes (in 2004, 2009) and minor amendments (see Hoppmann et al., 2014, for an excellent description). To accommodate industry complaints, EEG-adjustments increasingly exempted commercial actors from paying the EEG-surcharge, which meant that households carried more of the financial burden. The increasing consumer energy bills subsequently became an important argument of EEG-opponents ('Big-4', Ministry of Economic Affairs), leading to cost-reduction attempts from 2008 onwards (Hoppmann et al., 2014). Public support for renewables remained high, however, and RETs developed into a significant industrial activity, which increased industrial policy interest at state and local levels.

4.2.2.2. Actors and technologies. The renewables expansion coincided with a 'social opening up' of the electricity sector (Mautz et al., 2008), resulting from increasing numbers of new entrants and the creation of new associations that helped professionalize the renewables sector. Incumbent utilities continued to play a limited role in RETs. Most renewables growth came from four RETs:

- ***Onshore wind*** continued its expansion (Fig. 4), with more actors deploying wind turbines for economic reasons. As the wind sector professionalized, the heterogeneity of actors decreased.
- The expansion in ***biogenic solid fuel*** was initially driven by municipal utilities (trend:research, 2011), which built on their experience with medium-sized infrastructure. Some municipal utilities joined forces to develop countervailing power against the Big-4, leading to larger coalitions that jointly operated plants and exerted political influence (Bontrup and Marquardt, 2011).
- ***Biogas*** expanded rapidly after 2006 (Fig. 4), with most new farmers being motivated by economic considerations such as attractive financial incentives in the EEG-2004 and low agricultural prices, which stimulated diversification. Professional associations (Fachverband Biogas) additionally provided technical and procedural support (Mautz et al., 2008).
- ***Solar-PV*** deployment was stimulated by the federal 100.000-roof program, introduced in 1999, and by EEG-support. Rapid diffusion after 2006 (Fig. 4) was carried by different actors. Small-scale solar-PV systems were deployed by citizens; large-scale roof- and field-mounted systems were mainly deployed by farmers; centralized PV power systems were mainly deployed by project developers (Dewald and Truffer, 2011). Solar-PV developed into an industrial success story, as total sales of the German PV industry grew from 201 million euro in 2000 to 7 billion euro in 2008. Export sales grew from 273 million euro in 2004 to approximately 5 billion euro in 2010 (BSW-Solar, 2010).

4.3. The niche-regime 'battle' intensifies (2009–2014)

4.3.1. Regime dynamics

4.3.1.1. Actors and institutions. The newly elected (2009) center-right government (CDU/CSU/FDP) overturned the previous nuclear phase-out decision in 2010. This decision was welcomed by the utilities, but triggered heated public debates and large anti-nuclear protests. In 2010, the government published an ambitious 'Energy

Table 2
German ownership structure (%) of installed capacity of different renewable electricity technologies in 2010 (from: trend:research, 2011).

	Households	Farmers	Banks, funds	Project developers	Municipal utilities	Industry	Four major utilities	Others
Wind	51.5	1.8	15.5	21.3	3.4	2.3	2.1	2.2
Biogas	0.1	71.5	6.2	13.1	3.1	0.1	0.1	5.7
Biomass	2.0	0	3.0	6.9	24.3	41.5	9.6	12.7
PV	39.3	21.2	8.1	8.3	2.6	19.2	0.2	1.1

Concept', which the opposition claimed was meant to appease public opinion. The energy concept proposed that renewable electricity generation would increase to 35% in 2020, 40–45% by 2025, 55–60% by 2035 and 80% by 2050 (Lauber and Jacobsson, 2016). In 2011, the Fukushima nuclear accident caused major public uproar, in response to which the government immediately closed eight of seventeen nuclear plants, with the remainder being phased out in a staged process between 2015 and 2022. The nuclear phase-out also gave rise to the *Energiewende*, an explicit energy transition policy that formally adopted the renewable electricity targets from the 'Energy Concept'.

Meanwhile, the utilities faced serious economic problems because of several developments (Kungl, 2015): (1) the financial-economic crisis reduced electricity demand, which caused over-supply, (2) renewable electricity expansion reduced the market share of incumbent utilities, (3) renewable electricity expansion reduced the electricity wholesale price due to the merit order effect[6], leading to gas displacement, (4) the closure of nuclear reactors left utilities with stranded assets. These economic problems caused utility share prices to drop by 60–70% between 2008 and 2013 (Fig. 7) and led utilities to question their business models. The CEO of EnBW stated in its 2012 annual report: "I see a paradigm shift in the energy sector that questions the traditional business model of many power supply companies." A confidential paper titled 'RWE's Corporate Story' raised gloomy prospects: "The massive erosion of the wholesale prices caused by the growth of German photovoltaics constitutes a serious problem for RWE which may even threaten the company's survival" (Energy Post, October 21, 2013).

These problems also worried the government, which therefore attempted to slow down renewables expansion (see below), while strengthening support for utilities and conventional power plants. The latter were increasingly framed as complementary to RETs and as necessary (in the short to medium-term) for guaranteeing the stability of the electricity system. Attention turned to new policies like 'capacity markets', which would reward utilities for providing the *availability* rather than use of generating capacity (Wassermann et al., 2015).

4.3.1.2. Actors and technology. ***Nuclear power*** steeply declined after 2011, with the resulting gap being filled by expanding renewable electricity and increased use of domestic lignite and international hard ***coal*** (Fig. 6). Combined with down-scaled ***gas*** use, German CO2-emissions from power-generation increased from 304 Mt CO2 in 2011 to 317 Mt CO2 in 2013[7]. Local protests and political uncertainties led utilities (RWE, Vattenfall) to cancel their plans for Carbon Capture and Storage (Pietzner and Schumann, 2012).

The utilities belatedly diversified into ***renewable energy*** production: RWE founded RWE Innogy (2007), Vattenfall created Vattenfall Europe New Energy (2007) and a Wind sub-division (2009), E.ON founded E.ON Climate and Renewables (2008) and EnBW launched EnBW Renewables (2008). These renewable energy activities mainly happened in foreign markets (e.g. UK offshore wind), so involvement in Germany remained small, with only 6.5% of renewable electricity being produced by the Big-4 in 2010, which mainly comprised of hydro-power, biomass and some offshore wind (trend:research, 2011).

4.3.2. Renewable niche innovations

4.3.2.1. Actors and technology. Renewable electricity expansion was accompanied by social broadening of RET-deployment. Municipal utilities became an important actor (especially in biomass), with the number of newly founded municipal utilities rising from 23 between 2005 and 2008 to 59 between 2009 and 2012 (Berlo and Wagner, 2013). Citizen energy cooperatives also expanded rapidly. In 2012, 754 energy cooperatives were listed in cooperative registries, with 199 created in 2012 alone (Holstenkamp and Müller, 2013). Farmers also increasingly engaged with RETs for commercial reasons, both in biogas and large-scale solar-PV. Table 2 demonstrates the broad social base, represented in terms of relative ownership.

Renewables growth mainly came from three RETs:

- ***Onshore wind*** continued to expand (Fig. 4), operated by utilities, cooperatives, and investors.
- ***Biogas*** continued to grow, as EEG-support attracted mainstream farmers. The German Farmers' Association and the German Biogas Association facilitated diffusion by offering legal and technical advice with regard to market and system integration (Hahn et al., 2014). The 2012 and 2014 EEG-amendments slowed growth, however, because of new technical prescriptions and reduced financial support (German Biogas Association, 2014; Agentur für Erneuerbare Energien 2015).
- ***Solar-PV*** showed faster-than-expected growth (from 6.6 TW h electricity in 2009 to to 34.9 TW h in 2014), because of high citizen interest, EEG-support, and decreasing PV-module prices, resulting from Chinese mass production, over-production and price dumping (Lauber and Jacobsson, 2016). Cheap Chinese imports created economic problems for German manufacturers of PV-modules[8], which led to critical debates (about EEG subsidizing Chinese manufacturers). The substantial 2012 EEG-adjustments slowed the growth in solar-PV deployment rate (Fig. 4). The 2014 EEG-amendment further slowed expansion, with the rate of new installations falling behind the government's expansion plans in the first half of 2015[9].
- The government also tried to stimulate ***offshore wind***, which fitted incumbent utilities because of size and cost structures. In 2010, the government increased the EEG remuneration rate and set ambitious expansion targets (10 GW by 2020). Offshore wind deployment remained relatively small, however, with only eight offshore wind parks in operation by the end of 2014 (916 MW

[6] The merit order refers to the ranking of sources of electricity generation, in ascending order of short-run marginal production costs. Electricity sources with the lowest marginal costs (renewable electricity) are first brought online to meet demand.

[7] Based on statistics from the Federal Environmental Agency; http://www.umweltbundesamt.de/sites/default/files/medien/376/publikationen/climate_change_23_2014_komplett.pdf.

[8] German producers of inverters, manufacturing equipment and poly-silicon production fared somewhat better (Hoppmann et al., 2014).

[9] See: http://www.iwr.de/news.php?id=29163.

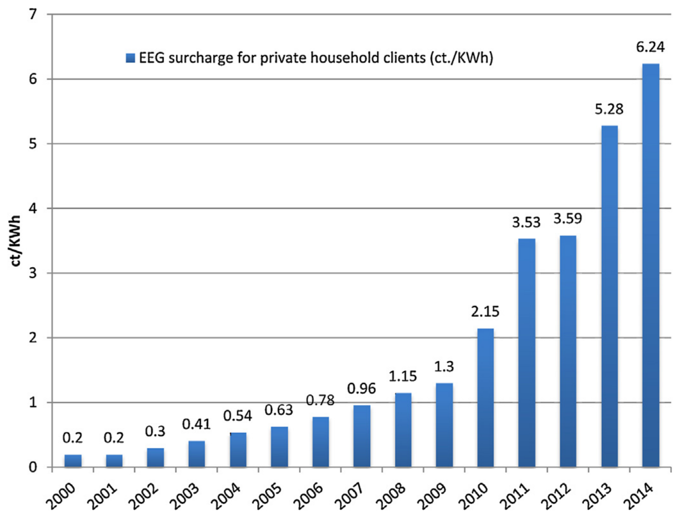

Fig. 8. EEG surcharge for private households (ct/kW h) (BDEW, 2014).

installed capacity) and eleven more under construction. Reasons for the slow development were problems with grid access and technical challenges of deep water construction, which drove up costs (Reichardt et al., 2015). In the 2014 EEG adjustments, the government downscaled support for offshore wind.

4.3.2.2. Actors and institutions. The renewables support coalitions weakened in this period (Lauber and Jacobsson, 2016), because German RET-industries faced problems due to Chinese competition. RETs also faced operational and cost challenges, which led to struggles and rule adjustments. First, EEG-surcharges increased rapidly since 2009 (Fig. 8), with half of the EEG surcharge being used to support solar-PV (Hoppmann et al., 2014). The rise in consumer electricity prices led to critical debates about renewables, with utilities highlighting threats to the economy and undesirable impacts on poor households. These arguments resonated with the CDU/FDP government, which made various adjustments in the EEG (Hoppmann et al., 2014). The substantial 2012 amendments lowered EEG-support, which created uncertainty amongst investors in solar-PV and wind (Stegen and Seel, 2013).

Second, increasing amounts of intermittent RETs (wind, solar) created concerns about 'system integration' and grid stability. Incumbent utilities reinforced these fears, warning for black-out risks[10]. To address system integration, research activities began focusing on demand side management and energy storage (BMWi/BMU/BMBF, 2011). It remained challenging, however, to develop business models for commercially viable energy storage and policies that would attract investments (BDEW, 2013).

Third, intermittent RETs created 'market integration' problems, because their operational characteristics disrupted 'normal' market functioning (for instance negative prices on sunny, windy days when renewables produced more power than consumers demanded). To facilitate market integration of RETs, the government introduced new policies to stimulate direct marketing of renewable electricity[11], e.g. an 'optional market premium' and a 'flexibility premium' mechanism (Wassermann et al., 2015).

[10] RWE's CEO, for instance, warned that renewables could lead to black-outs, stating that he was "really worried" because "everywhere with high speed more plants will be taken from the grid". E.ON further warned for a "wave of decommissioning" and "hazards for electricity supply" (Spiegel, October 29, 2013, own translation).

[11] Direct marketing transfers the task of selling renewable electricity from the transmission system operator to renewable plant operators.

The various rule changes aimed to slow renewables expansion and make RETs more compatibile with the existing electricity system (through system and market integration). It proved difficult, however, to contain the renewables 'genie' once it was out of the bottle (Fig. 1). In 2014, the government therefore made further changes. It transferred EEG-responsibility back to the Economics Ministry and substantially amended the EEG, setting upper limits for RET-expansion. To 'manage' renewables expansion, the government also significantly lowered EEG-remunerations, said it would end bioenergy subsidies, articulated upper limits for offshore wind expansion, and stated intentions to introduce auction systems. These policy changes disadvantage many new entrants and favour larger actors skilled in handling auctions, marketing, and network management.

Having analysed the German low-carbon transition along our conceptual categories, we now turn to the UK case. Section 6 then makes a comparative analysis of both countries in relation to the two conceptual contributions.

5. The UK low-carbon electricity transition

5.1. Slow RET-developments in privatised regime context (1990–2002)

5.1.1. Regime dynamics

5.1.1.1. Actors and institutions. The UK electricity industry was privatised (1990) and liberalized (1998), which eventually resulted in the 'Big Six' electricity companies (EDF, E.ON, SSE, British Gas, Scottish Power, N-Power). Their guiding principles came to focus on price competition, sweating assets and fuel flexibility (Pearson and Watson, 2012).

The government increasingly adopted a hands-off approach, leaving decisions to the market. The Department of Energy was therefore disbanded in 1992, relegating energy policy to a subdivision of the Department of Trade and Industry (DTI). To depoliticize energy governance, DTI set the regulatory framework, but left implementation to the newly created independent regulator Ofgem. Ofgem's main remit was to ensure that markets were sufficiently competitive and to protect consumer interests (Kern et al., 2014b).

5.1.1.2. Actors and technology. In the 1990s, utilities switched from coal to natural gas (Fig. 9). This 'dash for ***gas***' was stimulated by various factors (Pearson and Watson, 2012): utility preferences for

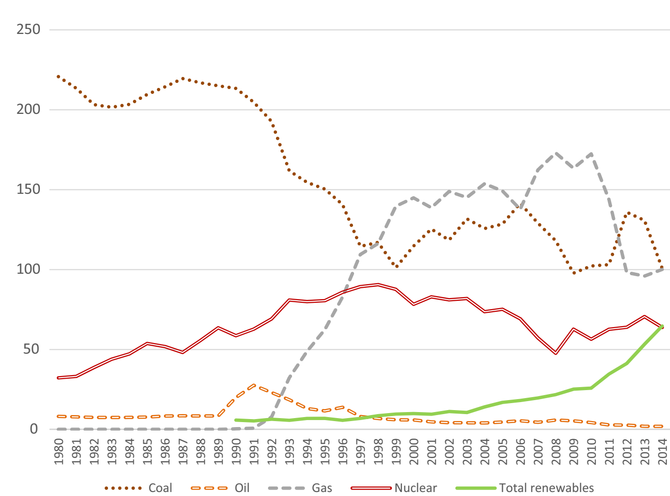

Fig. 9. UK electricity generation by fuel type, 1990–2014, in TW h (data from DUKES).

power generation units with short lead times, low capital costs, and quick returns on investment, which aligned well with combined cycle gas turbines (CCGT); price/performance improvements in CCGT; new North sea gas finds and cheap international gas; environmental benefits of gas compared to coal.

Coal-fired power generation was perceived to be on its way out in the 1990s (Turnheim, 2012), because of the 'dash for gas', pressures from the European Large Combustion Plants Directive (LCPD), which prescribed reductions in SO2 emissions, and pressures from climate change.

Nuclear power also faced difficulties when preparation for privatization revealed its poor economic performance. Scandals connected with the storage of nuclear waste (Sellafield) and reprocessing further undermined its legitimacy (Verhees, 2012). In 1989, the government withdrew nuclear power plants from privatisation plans and announced a moratorium on new nuclear plants. In 1990, the government introduced the Non-Fossil Fuels Obligation (NFFO), which required electricity companies to buy certain amounts of nuclear power for which they were compensated with a subsidy paid from a Fossil Fuel Levy. In 1996, the government sold the nuclear plants to British Energy, which had to be bailed out in 2002 when declining electricity prices created financial problems (Hewlett, 2005)[12].

5.1.2. Renewable niche-innovations

5.1.2.1. Actors and institutions. Support for RETs emerged as a 'side-effect' (Toke and Lauber, 2007) of the NFFO, when renewables' advocates argued that RETs should also qualify for non-fossil fuel subsidies. The government obliged, although it had no clear renewables strategy (Mitchell and Connor, 2004). The NFFO policy for renewables, which was intended to run from 1990 to 1998, was a competitive auction system in five different rounds. Bidders could submit proposals to produce a certain amount of renewable electricity for a certain price. In each round, the government awarded contracts to the lowest bidders (Mitchell and Connor, 2004). The NFFO-bidding process was complicated, requiring sophisticated financial capabilities and sufficient capital to cope with the economic risks and policy uncertainties. These characteristics favoured professional corporate actors and discriminated against smaller new entrants with less-developed procedural and financial capabilities and resources (Toke, 2005; Mitchell and Connor, 2004).

The NFFO was limitedly effective because many accepted bids never resulted in actual RET-deployment. This was due to the auction design, which stimulated bidders to submit very low cost proposals that were later found to be too uneconomical to be realised (Toke and Lauber, 2007). The completion rate of NFFO-projects decreased over time. Over the whole period (1990–2004), only 30% were actually completed (Wood and Dow, 2011).

5.1.2.2. Actors and technology. The NFFO produced slow growth of renewable electricity (from 1.9% in 1990 to 3.0% in 2002), mainly from ***landfill gas***, ***onshore wind*** and ***energy-from-waste*** (Fig. 5), which received continuous subsidy support over successive NFFO-rounds. These RETs, which were operated by large corporate actors (utilities, project developers, landfill site operators, waste companies), were also closest to market, which fitted the policy's short-term orientation and low-cost emphasis. Other RETs (e.g. energy crops, sewage gas) received intermittent support, which hampered investor confidence (Mitchell and Connor, 2004). RET-development by new entrants (cooperatives, farmers, local communities) remained limited. In 2004, only 1.5% of wind turbine capacity was owned by farmers and cooperatives, while 98% was operated by utilities and corporate independents (Toke, 2005).

Further problems occurred with regard to grid connection (which utilities made difficult for new entrants) and local implementation (because utilities and project developers engaged in poor consultation processes which gave rise to public opposition) (Wood and Dow, 2011). Local planning problems were partly related to the NFFO's bidding design: most developers did not start the planning permission process until after they were awarded the contract. They would then be in a hurry and install RETs without proper stakeholder consultation, which turned many stakeholders into opponents (Ellis et al., 2009). For onshore wind, this resulted in negative sentiments and perceptions of unfair distributions of costs (local stakeholders experiencing noise, visual burdens, shadow flicker) and benefits (project developers enjoying wind resources and financial gains).

5.2. Rising energy concerns in a neo-liberal context (2002–2008)

5.2.1. Regime dynamics

5.2.1.1. Actors and institutions. The Labour government, elected in 1997, made climate change an important issue for energy policy. The 2003 White Paper *Our Energy Future: Creating a Low-Carbon Economy* highlighted the need for a 60% reduction of GHG emissions by 2050 and committed to a target of 10% renewable electricity by 2010. It saw carbon pricing (via European emissions trading) as the main instrument.

Public attention to climate change increased rapidly in the mid-2000s, making it an attractive issue for high-level politicians to compete on (Carter and Jacobs, 2014). This competition resulted in cross-party consensus about the importance of climate change. Rising oil and gas prices (Fig. 10) and the Russia–Ukraine gas dispute in 2005 made costs and energy security important goals besides climate change in the 2007 White Paper *Meeting The Energy Challenge* (Kern et al., 2014b).

5.2.1.2. Actors and technologies. The 2003 White Paper was a blow for ***nuclear power***, because it stated that: "Its current economics make nuclear power an unattractive option for new, carbon-free generating capacity and there are also important issues of nuclear waste to be resolved" (p. 12). The White Paper further promised that new construction decisions would require "the fullest public consultation". In subsequent years, however, policymakers and advisers increasingly framed nuclear power as a solution for climate change and energy security (Verhees, 2012). The 2007 White Paper broadened government support from renewables to include nuclear power and coal with CCS. Greenpeace legally contested this

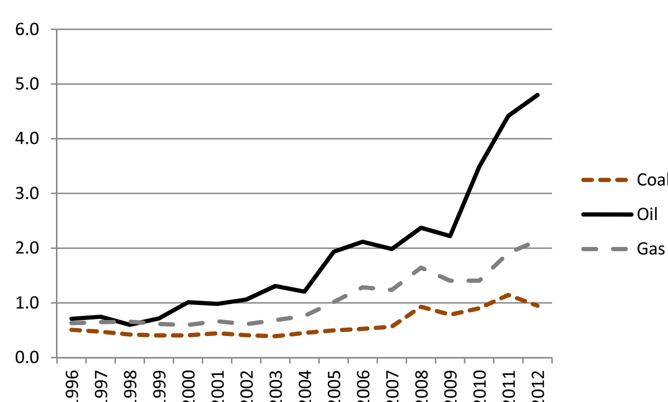

Fig. 10. Average fuel prices (pence per kWh) paid by UK power producers (quarterly energy prices from https://www.gov.uk/government/uploads/system/./qep_mar_2013.pdf http://www.decc.gov.uk/assets/decc/Statistics/publications/prices/1085-qepdec10.pdf, accessed on July 22, 2013).

[12] The government also took responsibility for nuclear waste management and decommissioning costs of around £3 billion (Hewlett, 2005).

revival of nuclear power, arguing that the government had failed to properly consult (Verhees, 2012). The court agreed and ordered the government to launch a new consultation. Prime Minister Blair, however, announced in advance that "This won't affect policy at all".

Coal-fired power plants faced pressure from climate change concerns and LCPD emission targets, which implied that most existing plants should close by 2015 (or had to heavily invest in flue gas desulphurisation). Rising gas prices, however, led utilities to burn more coal in existing plants between 2000 and 2006 (Fig. 9). Concerns about energy security also led the government to reconsider coal, with the trade and industry secretary stating: "If a new, cleaner coal generation is viable, then I think it could have an important part to play in making sure we have diverse generation in the future. Coal is easy to store and it comes from a variety of well-established sources around the world" (reported in *The Guardian*, 21 February 2006). These reconsiderations were legitimated with the promise of 'clean coal', based on flue gas desulfurization, supercritical pulverised coal technologies, coal gasification and CCS. The 2007 White Paper announced £1 billion subsidy for a CCS demonstration programme (Turnheim, 2012).

5.2.2. Renewable niche-innovations

5.2.2.1. Actors and institutions. While emissions-trading was the main climate policy instrument, the government also introduced the Renewables Obligation (RO) in 2002, which required utilities to meet annual renewable electricity targets, which increased to 10% in 2010. Utilities could meet these targets in several ways: (a) generate renewable electricity themselves, (b) buy Renewable Obligation Certificates (ROCs) from other generators, (c) pay a 'buy-out' penalty of 3p/kW h.

The RO was more market-oriented than the NFFO, because it was based on free-market trading of ROCs and abolished the NFFO's technology banding. Because all RETs received the same number of ROCs, the RO was biased towards cheaper (large-scale) technologies such as onshore wind and landfill gas. Small-scale producers and independents raised concerns about this discrimination and proposed 'bands' for different RETs. DTI-officials rejected these proposals, arguing that governments should 'not pick winners' but leave technology choices to the market (Foxon and Pearson, 2007).

Although renewable electricity grew from 3.0% in 2002 to 5.8% in 2008, renewables policy had several flaws, including incentives for utilities to underperform (Toke, 2005), uncertainties over longer-term policy commitment (Wood and Dow, 2011), and neglect of innovation (Foxon and Pearson, 2007). The RO also favoured incumbents and discriminated against new entrants (Woodman and Mitchell, 2011), because ROC-trading created financial uncertainties (about future ROC prices and viability of investments), which were easier to manage for utilities with deep pockets.

5.2.2.2. Actors and technologies. Renewable electricity mainly came from four RETs (Fig. 5).

- ***Co-firing of biomass*** in coal plants grew rapidly after 2002, because it was relatively easy and cheap for utilities.
- ***Landfill gas***, which was deployed by landfill operators using mature technologies, slowed in the mid-2000s, because successive waste policies (landfill tax, EU Landfill Directive) reduced the amount of organic waste going to landfill.
- ***Energy-from-waste*** increased slowly because many projects encountered local permit problems.
- ***Onshore wind*** farms, operated primarily by utilities and project developers (Toke, 2005), accelerated after 2002 because the RO provided attractive financial support (Foxon and Pearson, 2007). However, many proposed wind projects encountered local opposition, because project developers paid limited attention to stakeholder concerns (Ellis et al., 2009). Consequently, the public discourse about wind became increasingly negative. Offshore wind, which is much more expensive than onshore wind, started tentatively in 2001 with a demonstration project in Blyth. Five other offshore wind farms, aimed at further learning, were constructed between 2003 and 2007, supported by capital grants (Kern et al., 2014a).

5.3. Increasing renewables momentum in more difficult socio-political contexts (2008–2014)

5.3.1. Regime dynamics

5.3.1.1. Actors and institutions. This period started with strong climate change commitments. In 2007, the government accepted the European 20-20-20 targets, which included a 20% share of renewables in *energy* consumption by 2020. In 2008, the government introduced the Climate Change Act which was a radical policy change (Carter and Jacobs, 2014) that legally committed the UK to 80% GHG reduction by 2050 and 34% reduction by 2020. In 2008, the government also created the Department of Energy and Climate Change (DECC) and the independent Committee on Climate Change (CCC), with responsibilities for advising the government about progress towards climate change targets.

The translation of high-level goals into more specific targets and plans created a policy delivery momentum. For the electricity sector, the UK Low Carbon Transition Plan (2009) articulated a target of 30% renewable electricity by 2020 and an almost complete decarbonisation by 2030. Other implementation-oriented documents were the amended Renewables Obligation (2009), the UK Renewable Energy Strategy (2009), the Carbon Plan (2011), the Energy Bill (2012) and the Electricity Market Reform (2013). The various policies represented a move from a hands-off approach to higher degrees of interventionism (Lockwood, 2013; Kern et al., 2014b).

While *policy* momentum increased, the transition also faced *political* counter-trends, which gathered pace after the financial-economic crisis and the election of a new Conservative-Liberal Democrat government in 2010. First, public attention to climate change diminished, leading politicians to realize that they were ahead of their voters (Lockwood, 2013). Especially the right-wing of the Conservative party became more vocal, criticizing subsidies for onshore wind and questioning climate change science. Second, the financial-economic crisis enhanced concerns about jobs, competitiveness and energy prices. The Treasury used these concerns to regain influence over climate policy (Carter and Jacobs, 2014), issuing warnings that green policies should not hinder the economy. In 2013, cost concerns escalated into a full-scale political row over rising energy bills, which led the government to scrap, delay or water down various green policies. Third, the government refused to commit to long-term renewable electricity targets beyond 2020, despite repeated recommendations from the Committee on Climate Change.

5.3.1.2. Actors and technology. The 2008 *White Paper on Nuclear Energy* announced plans to construct eight new ***nuclear power*** reactors by 2025 (Verhees, 2012). Public opposition was limited, partly because the environmental movement was divided, with some activists (e.g. Stephen Tindale, George Monbiot, Mark Lynas) perceiving nuclear power as a necessary evil to address climate change. Private companies showed lukewarm interest because waste processing liabilities, decommissioning costs, and unclear future electricity prices created uncertainties about the viability of nuclear investments, especially since the government had repeatedly ruled out subsidies. In 2013, the energy company Centrica abandoned new construction plans, leaving only EDF in negotiations with the UK government about a 3.2 GW plant at Hinkley Point. To enable the deal, the government broke its non-subsidy pledge, agreeing to pay EDF a guaranteed price (£92.50 per MW h, twice the wholesale price) for 35 years. To enable future construction, the new Contracts-for-Difference (see below) offered attractive incentives for nuclear power (Toke, 2013). At the time of writing, the nuclear programme is already 5 years behind schedule, compared to the 2008 ambitions, making it unlikely that the government will reach its stated aims for 2025.

The government also strengthened its commitment to ***natural gas***, inspired by the US shale gas revolution. In 2012, the government lifted restrictions on fracking. In 2013, the Chancellor promised tax breaks for shale gas companies, arguing that shale gas "has the potential to create thousands of jobs and keep energy bills low for millions of people." In 2013, the government also expressed desires for building forty gas-fired power stations, which the Committee on Climate Change warned would be incompatible with climate change targets. Despite heated local protests against fracking, the government decided to move ahead, with the Prime Minister personally expressing strong commitment in a letter to *The Telegraph*, dismissing protesters as uninformed NIMBY-activists (11 August 2013).

By 2008, utilities were seeking approval for new ***coal***-fired power plants, totalling over 11 GW, to replace plants that would be phased out by 2015/16 (Turnheim, 2012). These plans would threaten climate change ambitions and triggered public opposition from activist groups like Climate Camp, which campaigned against a new plant at Kingsnorth. In 2009, DECC announced that no new coal-fired plants would be permitted unless they incorporated Carbon Capture and Storage (CCS). Although the government's £1 billion subsidy for CCS demonstration projects triggered some interest from energy companies, no projects materialized. Meanwhile, coal use in *exising* plants increased, especially in 2012 when coal use increased by 32% in one year (from 103.1 to 135.9 TW h). Coal use decreased substantially in 2013 and 2014 (Fig. 9), as some coal-fired plants were (partially) converted to biomass (Drax, Ironbridge) or closed (Kingsnorth, Cockenzie, Tilbury Didcot, Uskmouth, Ferrybridge) because of LCPD-legislation and end-of-life considerations.

5.3.2. Renewable niche-innovations

5.3.2.1. Actors and institutions. The political salience of climate change increased criticism of the limited effectiveness of the Renewables Obligation, which resulted in an amended Renewables Obligation (2009) that included technology banding, which allocated varying amounts of ROCs to different technologies, depending on degree of maturity and level of risk. In 2010, the government reluctantly introduced a Feed-in-Tariff (FiT) as part of a political deal with backbenchers, who wanted a stimulus for small-scale renewables in exchange for their support for nuclear and offshore wind (Smith et al., 2013). In 2011, the Treasury established the Levy Control Framework (LCF), which enabled it to control financial spending by DECC on levy-funded schemes such as the RO, FiT and Contracts-for-Difference (CfD). The Electricity Market Reform process provided attractive incentives for large-scale renewables and nuclear power through CfDs (from 2017 onwards). The 2013 Solar PV Strategy and 2014 Community Energy Strategy also paid some attention to small-scale renewables.

5.3.2.2. Actors and technologies. The rapid expansion of renewable electricity mainly came from three RETs (Fig. 5).

- ***Onshore wind*** continued to expand, with some increase in community energy since the mid-2000s[13]. The public discourse about wind became increasingly negative, because of concerns about subsidies, visual/landscape impacts, and the perceived invasion of the countryside by corporate interests (Kern et al., 2014a). These concerns gave rise to opposition from the Campaign to Protect Rural England and Conservative MPs, one hundred of whom wrote an open letter to the Prime Minister arguing against wind subsidies (5 February 2012). Local opposition against wind-farm proposals decreased approval rates in planning procedures from 73% in 2007 to 50% in 2012 (Committee on Climate Change, 2013).
- The deployment of ***offshore wind*** (OSW) accelerated with the amended RO, which provided attractive support (Hepstonstall et al., 2012). Annual installed capacity grew rapidly from 0.2 GW in 2008 to 1.2 GW in 2012, 0.7 GW in 2013 and 0.8 GW in 2014, making the UK the world leader in OSW-deployment. Kern et al. (2014a) suggest that OSW, which is one of the most expensive RETs, was pushed by a powerful coalition of actors, including DECC, BIS, the Crown Estate and utilities.
- Deployment of ***biogenic solid fuel*** accelerated rapidly after the *UK Bioenergy Strategy* (DECC, 2012), which shifted emphasis from relatively small-scale (<50 MW) *dedicated* biomass plants, operated by new entrants (e.g. sawmills, poulty farms), towards the *conversion* of coal plants into biomass-burning plants. These converted plants are large-scale facilities (e.g. Tilbury 750 MW, Drax, 1980 MW, Ironbridge 1000 MW), which require some technical adjustments, but enable coal plant operators to extend the plant's lifetime. This new strategy triggered a public controversy about the sustainability of industrial-scale 'Big Biomass'. Environmental organizations criticized the government in a 2012 report (*Dirtier than Coal?*), arguing that imported bio-crops have indirect land-use, bio-diversity and carbon impacts. In 2013, the opening of the (partly) converted Drax-plant triggered protest marches and led Friends of the Earth to question the legality of government aid to Drax (£75 million loan guarantees) with the European Commission. In 2014, the government admitted that it had made a mistake in calculating carbon savings from large-scale biomass (DECC, 2014), and said that policies would be adjusted.

The deployment of ***solar-PV*** greatly accelerated since the 2010 FiT. Although still relatively small, power generation almost doubled between 2013 and 2014 to 4.1 TW h (Fig. 5). Growth was fastest in the small-scale segment for domestic rooftops (<4 kW), although large utility-scale solar farms (>5 MW) also grew rapidly, which raised concerns about the effects on renewable subsidies and social acceptance.

In sum, large-scale RETs diffused rapidly in this period, supported by coalitions of large corporate actors and policymakers. Onshore wind and Big Biomass, however, encountered resistance from civil society actors, environmental NGOs, and local citizens.

6. Discussion

6.1. Endogenously enacted transition pathways in context

The German and UK electricity transitions, analysed above, clearly differ substantially in terms of enactment and the *kinds* of transition pathways pursued. This section aims to demonstrate the fruitfulness of the reformulated transition pathways, using the analytical categories to interpret and explain these differences.

In terms of overall transition patterns, we suggest that Germany followed a *substitution* pathway ('unleashing new entrants'). In terms of technologies, small-scale RETs (solar-PV, biogas, small

[13] Strachan et al. (2015: 105), however, conclude that "community renewables remain weakly developed in the UK", partly because of limited organizational capacities, and partly because of "the persistence of key features of socio-technical regime for electricity provision, which continues to favour large corporations and major facilities" (p 106).

onshore wind) competed with regime technologies from which they deviated in terms of knowledge base and operational principles (decentralized)[14]. This pattern is explained by the other two categories (actors and institutions). German RET-deployment was enacted by radically new entrants (citizens, cooperatives, environmental activists, farmers, municipal utilities), who preferred small-scale RETs and, in the first period, were inspired by social, environmental and anti-nuclear motivations. In the second and third period, financial motivations gained importance. Support coalitions for RET-deployment also included industrial associations from the metal and machine-building sector, RET-manufacturers, and policymakers interested in green jobs. The 1990 Feed-in-Law offered protection for new entrants and small-scale RET-deployment (mainly wind), while the 2000 EEG stimulated wider RET-diffusion, thereby 'unleashing' new entrants.

In contrast, we argue that the UK followed *a transformation* pathway, in which RET-deployment was mainly enacted by incumbent utilities, professional project developers and other corporate actors, motivated primarily by commercial motivations and regulatory compliance. Renewable electricity policies focused on incentivizing incumbents to deploy RETs rather than enabling new entrants. In fact, various auction and trading schemes created barriers for new entrants. RET policy instruments were also less stable and more complicated than in Germany, which favoured incumbents with larger balance sheets. The 2010 Feed-In-Tariff, the 2013 Solar PV Strategy and the 2014 Community Energy Strategy are recent add-on policies, aimed at small-scale RETs which complement rather than disrupt the focus on large-scale options (nuclear, offshore wind, CCS). These two categories (actors and institutions) help explain why renewable electricity mainly comes from large-scale RETs (offshore wind, onshore wind, conversion of coal plants to biomass, landfill gas), which required new technical knowledge, but fitted with centralized operational principles and business models of incumbents.

The enactment of these different transition pathways is further explained by static landscape characteristics that shaped action possibilities. Several societal deep-structures in Germany created positive affordance structures for RET-deployment by new entrants:

- Germany has a relatively strong and organized civil society with active cooperatives, citizen groups, activists, and socially engaged scientists.
- Germany's 'coordinated market economy' (Hall and Soskice, 2001) has a collaborative tradition for stakeholder interaction, which in various instances led the government to accommodate civil society pressure (e.g. protests in the late 1990s against proposed cancellation of the Feed-In-Law; demands for more RET-support in the 2000s; protests against nuclear power and shale gas in the early 2010s). The 'coordinated market economy' also usually implies close interactions between utility incumbents and the government, which were, however, disrupted by the Red-Green government, as we discuss below.
- Germany has a strong environmentalist tradition (Dryzek et al., 2002), which helps explain the cultural resonance of the renewable energy discourse and the presence of a Green Party in Parliament, which became part of the government from 1998 to 2005.
- The German economy has substantial manufacturing sectors, which meant that German firms could benefit economically from the electricity transition, building wind turbines, solar-PV modules and other RETs. The creation of jobs and new industries contributed to RET support coalitions and a credible 'green growth' discourse.

The UK has various societal deep structures that favoured the 'working with incumbents' pattern and made RET-deployment by new entrants more difficult.

- The UK has a Westminster political system, which is characterized by close-knit policy networks that are relatively open to incumbent industry actors but remain closed for outsiders and new entrants (Bailey, 2007). The closed policy networks not only hinder broad stakeholder engagement, but also facilitate an autocratic, top-down policy style: "The government in the UK is still meant to govern-full stop. (. . .) The government of the day acts. Others react. (. . .) Reforms (. . .) are not negotiated painstakingly with stakeholders. They are handed down from above by governments" (King, 2015: 283).
- The UK's 'liberal market economy' (Hall and Soskice, 2001) is characterized by a neo-liberal ideology, which explains the preference for market-based and non-technology specific policy instruments (NFFO, Renewables Obligation), which created barriers for new entrants. The emphasis on cost efficiency also helps explain the preference for close-to-market (large-scale) technologies.
- Civil society in the UK has weakened since the 1980s (Marquand, 2004). Although civil society engagement is vocal in some areas (e.g. animal welfare), it has been muted in the energy domain where "the level of grassroots activity has been very weak" (Toke, 2005: 373). In recent years, there has been somewhat more civil society activity (transition towns, community energy initiatives), leading the government to introduce a Community Energy Strategy in 2014.
- The UK has a weaker environmental tradition than Germany (Dryzek et al., 2002), although 'the countryside' has strong cultural connotations. The UK only has a small Green Party, which is also due to the first-past-the-post voting system.
- The UK has lost many manufacturing industries, which made it more difficult to develop a credible green industrial strategy, although policymakers have recently become more interested (as part of a wider 'economic rebalancing' discourse).

6.2. Shifts between transition pathways

A more detailed analysis also reveals shifts *between* transition pathways. In Germany, the main shift was from a 'stretch-and-transform' substitution pathway in the second period to a 'fit-and-conform' pathway in the third period. In the UK, the main shift was from limited to more substantial transformation as policy pressures increased in the third period. These shifts mainly resulted from struggles over rules in successive periods, which we briefly analyse below.

In the first period of the German transition, the 1990 Feed-in-Law provided shielding of new entrants against incumbent utilities, who fought back through legal contestations that created substantial uncertainty in the late 1990s. Had the courts ruled in favour of the incumbents, the German transition might have unfolded quite differently. In the second period, there was a strong push from new entrants for more RET-support, which the Red-Green government (1998–2005) was happy to provide via the EEG, which was a radical policy that introduced new goals, altered the rules of the game, and set the substitution pathway on a 'stretch-and-transform' course. The Red-Green government disrupted the previously cosy relations between utilities and government in some important respects such as the EEG, the nuclear phase-out decision (2002), and the transfer of energy policy from the Economics to the Environment

[14] Recent offshore wind efforts create some deviation from this pattern, as they are large-scale and mainly enacted by incumbent utilities.

Ministry[15]. In this period, the utilities tried to delegitimize RETs through discursive strategies (highlighting costs and insecurity), but focused more on economic possibilities (take-overs, mergers, international expansion) following liberalization of the electricity sector (1998). The Conservative-Social Democrat government (2005–2009) agreed to continue previous policies because by then a strong and broad domestic lobby had emerged (Lauber and Jacobsson, 2016).

In the third period, incumbent utilities engaged in a strong fight-back because RET-competition (combined with the effects of the recession and nuclear phase-out) created major financial-economic difficulties. The new Conservative-Liberal coalition (2009–2013) was sympathetic to their arguments leading to a socio-political discourse about costs, intermittency and market problems. This led to new policies (also under the Conservative-Social Democrat coalition since 2013) that downscaled EEG-support and emphasized market and system integration, which changed the transition to a 'fit-and-conform' substitution pathway because RETs are required to adapt to regime-oriented market rules. The 'layering' of capacity market policies even opened prospects for a reconfiguration pathway in which coal can co-exist with renewables.

Shifts in UK transition pathways mainly refer to changing depths of incumbent reorientation based on varying policy pressure. In the first period, reorientation towards renewables was limited, because the ad-hoc NFFO policy exerted weak pressure, especially compared to privatisation and the dash-for-gas. In the second period, reorientation became somewhat more substantial, as the Labour government introduced climate change as an important policy goal and introduced the Renewables Obligation, which created pressure on utilities but also opportunities in terms of investment. Renewables performance remained below targets, however, because the RO was *layered* onto existing neo-liberal rules and principles and had several design flaws. Climate change gained political momentum in the mid-2000s, because high-level politicians chose to compete on the issue (Carter and Jacobs, 2014), which resulted in the ambitious 2008 Climate Change Act. The third period was characterized by more interventionist policies with stronger targets and attractive financial incentives that stimulated more substantial engagement from utilities, project developers and investors. However, the third period also saw a political controversy over rising energy prices, which eroded green ambitions.

In July 2015, these political counter-trends culminated in decisions by the newly elected Conservative government to slash support for onshore wind, solar-PV (especially 1–5 MW installations), and biomass plants. Although these policy changes falls outside the scope of analysis, they are likely to shift the transformation pathway back to less substantial renewables reorientation. The government's long-term vision of a low-carbon transition seems oriented towards a 'partial reorientation' (Table 1), based on some large-scale RETs (around 30% of electricity generation), and expansion of nuclear power and coal/gas with CCS. These developments suggest that utilities are likely to remain core actors in the UK low-carbon transition. More generally, the UK coalition between utilities and the government has remained fairly strong throughout the period, which helps explain, first, why UK renewables policy was formulated to suit the interests of utilities and created barriers for new entrants, and, second, why UK climate policy envisages a continued role for regime technologies. New entrants complained about regulatory and economic entry barriers, but gained limited traction with policymakers. The closed policy networks and top-down policies did, however, create public controversies in the societal embedding of onshore wind, Big Biomass and shale gas/fracking because of a 'bulldozer' policy style that pushes through concocted plans rather than consulting with citizens and societal actors.

[15] The Red-Green government also made large concessions to the incumbents, for instance supporting large mergers despite concerns from cartel authorities.

7. Conclusions

The paper has made two contributions to the sustainability transitions literature and in particular the Geels and Schot (2007) transition pathway typology. First, it has reformulated this typology in terms of endogenous enactment, articulating the main causal mechanisms for actors, formal institutions, and technologies. This reformulation also led to further differentiation of the technological substitution and transformation pathways. Second, it explored the possibility of shifts *between* transition pathways, based on actor struggles over technology deployment and institutions, and proposed several possible shifts. This second contribution emphasizes the non-linearity of transitions, which are likely to unfold unevenly through sudden advances and setbacks, depending on changing coalitions and contexts, unintended consequences and learning processes.

Both contributions were supported with a comparative case study of the unfolding German and UK electricity transitions. The analysis showed that the German transition so far followed a technological substitution pattern, which is enacted by new entrants, deploying mainly small-scale RETs. The UK transition was found to follow a transformation pathway, which is enacted by incumbent actors, deploying mainly large-scale RETs. Further analysis showed that the German transition recently shifted from a 'stretch-and-transform' substitution pathway to a 'fit-and-conform' pathway, because of weakening support policies and system and market integration requirements. The UK transition gradually shifted towards deeper transformation and reorientation patterns, as policies became stronger and more interventionist. However, recent politicization of cost concerns and weakening renewables policies may trigger a shift back to a less substantial transformation pathway.

Regarding future developments, we suggest that German renewable electricity will continue to expand (although at a slower rate), because of continued high public legitimacy and an economic support base. Such expansion will, however, require successful market and system integration of RETs. For the UK, we suggest that the 2020 renewable electricity target (30%) is likely to be met, because much political capital has been invested. But the recent downscaling of RET-support is likely to slow down incumbent reorientation towards renewables. The UK's commitment to low-carbon *regime* options carries serious risks of not meeting longer-term climate change targets, because nuclear plans already experience major delays (at least 5 years), shale-gas exploitation is more difficult than in the US (and conflicts with climate change targets), and CCS is still commercially uncertain and progressing slower than anticipated.

We hope that our paper may open up fruitful areas of future research such as country-comparative research and 'comprehensive transition analysis' that addresses *multiple* niche-innovations and the existing regime. We also think that societal deep structures (or *static* landscape characteristics) warrant further attention, especially for country comparisons. Conceptually, we hope that our paper leads to further research on patterns of agency in transition pathways, which goes beyond established dichotomies (such as new entrants versus incumbents) and which pays attention to ongoing struggles between actors over institutions and technology deployment. We have shown how these struggles (and changing contexts) may lead to shifts between transition pathways, which not only entail steps forwards or backwards, but also shifts in direction and qualitative characteristics. More work could be done on systematization of shifts between transition pathways, as our paper has been somewhat inductive in delineating the phenomenon. These issues are particularly fruitful research topics, as struggles over the speed and character low-carbon transition appear to heat up in many countries and globally.

Acknowledgements

This work has been supported by the Centre on Innovation and Energy Demand, which is funded by the EPSRC/ESRC (grant number EP/KO11790/1), by the European Union's Seventh Framework Programme (FP7/2007-2013) under grant agreement no. 603942 (PATHWAYS), and by a guest professorship, funded by the Helmhoz Foundation ENERGY TRANS project. We want to thank the three reviewers for their thoughtful comments on a previous version.

References

Archer, M., 1982. Morphogenesis versus structuration: on combining structure and action. Br. J. Sociol. 33 (4), 455–483.
Bailey, I., 2007. Market environmentalism, new environmental policy instruments, and climate change policy in the United Kingdom and Germany. Ann. Assoc. Am. Geogr. 97 (3), 530–550.
BDEW, 2013. Stellungnahmen zum Thesenpapier 4. EEG Dialogforum: Die Rolle von Speichern in der Energiewende, Berlin.
BDEW, 2014. Energie Info. Erneuerbare Energien und das EEG: Zahlen, Fakten, Grafiken. BDEW, Berlin.
Bergek, A., Berggren, C., Magnusson, T., Hobday, M., 2013. Technological discontinuities and the challenge for incumbent firm: destruction, disruption or creative accumulation? Res. Policy 42 (6–7), 1210–1224.
Berggren, C., Magnusson, T., Sushandoyo, D., 2015. Transition pathways revisited: established firms as multi-level actors in the heavy vehicle industry. Res. Policy 44 (5), 1017–1028.
Berkers, E., Geels, F.W., 2011. System innovation through stepwise reconfiguration: the case of technological transitions in Dutch greenhouse horticulture (1930–1980). Technol. Anal. Strateg. 23 (3), 227–247.
Berlo, K., Wagner, O., 2013. Stadtwerke-Neugründungen und Rekommunalisierungen. Energieversorgung in Kommunaler Verantwortung. Bewertung der 10 wichtigsten Ziele und deren Erreichbarkeit. Wuppertal Institut für Klima, Umwelt, Energie GmbH, Wuppertal.
BMWi/BMU/BMBF, 2011. 200 Million Euros for Research into Energy Storage, Joint Press Release, ⟨http://www.bmwi.de/EN/Press/press-releases,did=391256.html⟩.
Bontrup, H.J., Marquardt, R.M., 2011. Kritisches Handbuch der Deutschen Elektrizitätswirtschaft. Edition Sigma, Berlin.
BSW-Solar, 2010. Statistic Data on the German Photovoltaic Industry, ⟨http://en.solarwirtschaft.de/fileadmin/content_files/factsheet_pv_engl.pdf⟩ (accessed 31th May 2011).
Byzio, A., Heine, H., Mautz, R., Rosenbaum, W., 2002. Zwischen Solidarhandeln und Marktorientierung. Ökologische Innovationen in Selbstorganisierten Projekten–autofreies Wohnen, Car-Sharing und Windenergienutzung. Soziologisches Forschungsinstitut, Göttingen.
Carter, N., Jacobs, M., 2014. Explaining radical policy change: the case of climate change and energy policy under the British Labour Government 2006–2010. Public Admin. 92 (1), 125–141.
Committee on Climate Change, 2013. Meeting Carbon Budgets: 2013 Progress Report to Parliament.
DECC, 2012. UK Bioenergy Strategy. Department for Climate Change, London.
DECC, 2014. Life Cycle Impacts of Biomass Electricity in 2020. Department of Energy and Climate Change, London.
Dewald, U., Truffer, B., 2011. Market formation in technological innovation systems: diffusion of photovoltaic applications in Germany. Ind. Innov. 18 (3), 285–300.
Dolata, U., 2013. The Transformative Capacity of New Technologies: A Theory of Sociotechnical Change. Routledge, London.
Dryzek, J.S., Hunold, C., Schlosberg, D., Downes, D., Hernes, H.-K., 2002. Environmental transformation of the state: the USA, Norway, Germany and the UK. Pol. Stud. 50 (4), 569–682.
Ellis, G., Cowell, R., Warren, C., Strachan, P., Szarka, J., 2009. Expanding wind power: a problem of planning, or of perception? Plann. Theor. Pract. 10 (4), 521–547.
Freeman, C., Perez, C., 1988. Structural crisis of adjustment, business cycles and investment behaviour. In: Dosi, G., Freeman, C., Nelson, R., Silverberg, G., Soete, L. (Eds.), Technical Change and Economic Theory. Pinter, London, pp. 38–66.
Foxon, T., Pearson, P.J.G., 2007. Towards improved policy processes for promoting innovation in renewable electricity technologies in the UK. Energy Policy 35, 1539–1550.
Fuchs, G., Wassermann, S., 2008. Picking a winner? Innovation in photovoltaics and the political creation of niche markets. STI Stud. 4 (2), 93–113.
Geels, F.W., 2004. From sectoral systems of innovation to socio-technical systems: insights about dynamics and change from sociology and institutional theory. Res. Policy 33 (6–7), 897–920.
Geels, F.W., 2006. The hygienic transition from cesspools to sewer systems (1840–1930): the dynamics of regime transformation. Res. Policy 35 (7), 1069–1082.
Geels, F.W., Schot, J.W., 2007. Typology of sociotechnical transition pathways. Res. Policy 36 (3), 399–417.
Geels, F.W., Schot, J.W., 2010. The dynamics of transitions: a socio-technical perspective. In: Grin, J., Rotmans, J., Schot, J., Geels, F.W., Loorbach, D. (Eds.), Transitions to Sustainable Development: New Directions in the Study of Long Term Transformative Change. Routledge, New York, pp. 9–87.
Geels, F.W., 2014a. Regime resistance against low-carbon energy transitions: introducing politics and power in the multi-level perspective. Theor. Cult. Soc. 31 (5), 21–40.
Geels, F.W., 2014b. Reconceptualising the co-evolution of firms-in-industries and their environments: developing an inter-disciplinary triple embeddedness framework. Res. Policy 43 (2), 261–277.
Geels, F.W., Penna, C.C.R., 2015. Societal problems and industry reorientation: elaborating the dialectic issue life cycle (DILC) model and a case study of car safety in the USA (1900–1995). Res. Policy 44 (1), 67–82.
German Biogas Association, 2014. Biogas Segment Statistics 2014, Online: ⟨http://www.biogas.org/edcom/webfvb.nsf/id/DE_Branchenzahlen/$file/14-07-03_Biogas%20Branchenzahlen_2013-Prognose_2014_englisch.pdf⟩ (accessed 05.08.2014).
Hahn, H., Krautkremer, B., Hartmann, K., Wachendorf, M., 2014. Review of concepts for a demand-driven biogas supply for flexible power generation. Renewable Sustainable Energy Rev. 29, 383–393.
Hall, P.A., Soskice, D., 2001. Varieties of Capitalism: The Institutional Foundations of Comparative Advantage. Oxford University Press, Oxford.
Henderson, R.M., Clark, K.B., 1990. Architectural innovation: the reconfiguration of existing product technologies and the failure of established firms. Adm. Sci. Q. 35 (1), 9–30.
Hepstonstall, P., Gross, R., Greenacre, P., Cockerill, T., 2012. The cost of offshore wind: understanding the past and projecting the future. Energy Policy 41, 815–821.
Hewlett, J.G., 2005. De-regulated electric power markets and operating nuclear power plants: the case of British energy. Energy Policy 33 (18), 2293–2297.
Hoogma, R., Kemp, R., Schot, J., Truffer, B., 2002. Experimenting for Sustainable Transport: The Approach of Strategic Niche Management. Spon Press, London.
Holstenkamp, L., Müller, J.R., 2013. Zum Stand von Energiegenossenschaften in Deutschland, Ein statistischer Überblick zum 31. 12. 2012. Working Paper Series in Business and Law No. 14. Leuphana University, Lüneburg.
Hoppmann, J., Huenteler, J., Girod, B., 2014. Compulsive policy-making: the evolution of the German feed-in tariff system for photovoltaic power. Res. Policy 43 (8), 1422–1441.
Jacobsson, S., Lauber, V., 2006. The politics and policy of energy system transformation-explaining German diffusion of renewable energy technology. Energy Policy 34, 256–276.
Kern, F., Smith, A., Shaw, C., Raven, R., Verhees, B., 2014a. From laggard to leader: explaining offshore wind developments in the UK. Energy Policy 69, 635–646.
Kern, F., Kuzemko, C., Mitchell, C., 2014b. Measuring and explaining paradigm change: the case of UK energy policy. Policy Polit. 42 (4), 513–530.
King, A., 2015. Who Governs Britain? Penguin Random House, UK.
Kungl, G., 2015. Stewards or sticklers for change? Incumbent energy providers and the politics of the German energy transition. Energy Res. Soc. Sci. 8, 13–23.
Lauber, V., Jacobsson, S., 2016. The politics and economics of constructing, contesting and restricting socio-political space for renewables: the German renewable energy act. Environ. Innov. Soc. Trans. (in press).
Lockwood, M., 2013. The political sustainability of climate policy: the case of the UK climate change act. Global Environ. Change 23 (5), 1339–1348.
Mahoney, J., Thelen, K. (Eds.), 2010. Explaining Institutional Change: Ambiguity, Agency, and Power. Cambridge Press, New York, NY.
March, J.G., 1991. Exploration and exploitation in organizational learning. Organ. Sci. 2 (1), 71–87.
Marquand, D., 2004. The Decline of the Public: The Hollowing Out of Citizenship. Polity Press, Cambridge.
Mautz, R., Byzio, A., Rosenbaum, W., 2008. Auf dem Weg zur Energiewende. Die Entwicklung der Stromproduktion aus erneuerbaren Energien in Deutschland. Universitätsverlag Göttingen, Göttingen.
Meadowcroft, J., 2005. From welfare state to ecostate. In: Barry, J., Eckersley, R. (Eds.), The State and the Global Ecological Crisis. MIT Press, Cambridge, MA, pp. 3–23.
Mitchell, C., Connor, P.M., 2004. Renewable energy policy in the UK 1990–2003. Energy Policy 32 (17), 1935–1947.
Neukirch, M., 2010. Die Internationale Pionierphase der Windenergienutzung. Göttingen (Dissertation).
Newman, K.L., 2000. Organizational transformation during institutional upheaval. Acad. Mange. Rev. 25 (3), 602–619.
Meyer, A.D., 1982. Adapting to environmental jolts. Adm. Sci. Q. 27 (4), 515–537.
Pahle, M., 2010. Germany's dash for coal: exploring drivers and factors. Energy Policy 38 (7), 3431–3442.
Pearson, P., Watson, J., 2012. UK Energy Policy 1980–2010: A History and Lessons to be Learnt. Parliamentary Group for Energy Studies, London.
Pietzner, K., Schumann, D. (Eds.), 2012. Akzeptanzforschung zu CCS in Deutschland. Aktuelle Ergebnisse, Praxisrelevanz, Perspektiven. Oekom, München.

Poole, M.S., Van de Ven, A.H., 1989. Towards a general theory of innovation processes. In: Van de Ven, A.H., Angle, H.L., Poole, M.S. (Eds.), Research on the Management of Innovation: The Minnesota Studies. Harper & Row Publishers, New York, NY, pp. 637–662.
Reichardt, K., Rogge, K., Negro, S., 2015. Unpacking the policy processes for addressing systemic problems: the case of the technological innovation system of offshore wind in Germany. In: Fraunhofer ISI Working Paper. No. S2/2015.
Rip, A., Kemp, R., 1998. Technological change. In: Rayner, S., Malone, E.L. (Eds.), Human Choice and Climate Change, 2. Battelle Press, Columbus, OH, pp. 327–399.
Rothaermel, F.T., 2001. Complementary assets, strategic alliances, and the incumbent's advantage: an empirical study of industry and firm effects in the biopharmaceutical industry. Res. Policy 30 (8), 1235–1251.
Schneiberg, M., Lounsbury, M., 2008. Social movements and institutional analysis. In: Greenwood, R., Oliver, C., Andersen, S.K., Suddaby, R. (Eds.), The Sage Handbook of Organizational Institutionalism. Sage, CA, pp. 650–672.
Seyfang, G., Smith, A., 2007. Grassroots innovations for sustainable development: towards a new research and policy agenda. Environ. Pol. 16 (4), 583–603.
Smink, M.M., Hekkert, M.P., Negro, S.O., 2015. Keeping sustainable innovation on a leash? Exploring incumbents' institutional strategies. Bus. Strategy Environ. 24 (2), 86–101.
Smith, A., Raven, R., 2012. What is protective space? Reconsidering niches in transitions to sustainability. Res. Policy 41 (6), 1025–1036.
Smith, A., Kern, F., Raven, R., Verhees, B., 2013. Spaces for sustainable innovation: solar photovoltaic electricity in the UK. Technol. Forecast Soc. 81, 115–130.
Stegen, K.S., Seel, M., 2013. The winds of change: how wind firms assess Germany's energy transition. Energy Policy 61, 1481–1489.
Strachan, P.A., Cowell, R., Ellis, G., Sherry-Brennan, F., Toke, D., 2015. Promoting community renewable energy in a corporate energy world. Sustainable Dev. 23 (2), 96–109.
Tacke, F., 2004. Windenergie: Die Herausforderung: Gestern, Heute, Morgen. VDMA Verlag GmbH, Frankfurt.
Thelen, K., 2003. How institutions evolve: insights from comparative historical analysis. In: Mahoney, J., Rueschemeyer, D. (Eds.), Comparative Historical Analysis in the Social Sciences. Cambridge University Press, Cambridge, pp. 208–240.
Toke, D., 2005. Are green electricity certificates the way forward for renewable energy? An evaluation of the UK's renewables obligation in the context of international comparisons. Environ. Plann. C 23 (3), 361–375.
Toke, D., Lauber, V., 2007. Anglo Saxon and German approaches to neo-liberalism and environmental policy: the case of financing renewable energy. Geoforum 38 (4), 677–687.
Toke, D., 2013. Climate change and the nuclear securitisation of UK energy policy. Environ. Pol. 22 (4), 553–570.
trend:research, 2011. Marktakteure, Erneuerbare Energie Anlagen in der Stromerzeugung 2011. Im Rahmen des Forschungsprojektes: Genossenschaftliche Unterstützungsstrukturen für eine sozialräumliche Energiewirtschaft, Online: ⟨http://www.kni.de/pages/posts/neue-studie-bdquomarktakteure-erneuerbare-energien-anlagen-in-der-stromerzeugungldquo-32.php⟩ (accessed 23.03.2014).
Turnheim, B., 2012. The Destabilisation of Existing Regimes in Socio-Technical Transitions: Theoretical Explorations and In-Depth Case Studies of the British Coal Industry (1913–2010). SPRU, University of Sussex (Ph.D. Thesis).
Turnheim, B., Geels, F.W., 2013. The destabilisation of existing regimes: confronting a multi-dimensional framework with a case study of the British coal industry (1913–1967). Res. Policy 42 (10), 1749–1767.
Van Driel, H., Schot, J., 2005. Radical innovation as a multi-level process: introducing floating grain elevators in the port of Rotterdam. Technol. Cult. 46 (1), 51–76.
Verhees, B., 2012. Cultural Legitimacy and Innovation Journeys: A New Perspective Applied to Dutch and British Nuclear Power. Eindhoven University of Technology (Ph.D. Thesis).
Wassermann, S., Reeg, M., Nienhaus, K., 2015. Current challenges of Germany's energy transition project and competing strategies of challengers and incumbents: the case of direct marketing of electricity from renewable energy sources. Energy Policy 76, 66–75.
Wood, G., Dow, S., 2011. What lessons have been learned in reforming the renewables obligation? An analysis of internal and external failures in UK renewable energy policy. Energy Policy 39 (5), 2228–2244.
Woodman, B., Mitchell, C., 2011. Learning from experience? The development of the renewables obligation in England and Wales 2002–2010. Energy Policy 39 (7), 3914–3921.