Dancing with complexity: Making sense of decarbonisation, decentralisation, digitalisation and democratisation

Iain Soutar
Energy Policy Group, University of Exeter, Penryn TR10 9EZ

Abstract

Energy systems across the world are changing, not only in terms of the technologies involved, but also with respect to economic, social, geographic and political dimensions. This perspective examines how four key trends: decarbonisation, decentralisation, digitalisation and democratisation, collectively packaged as the 'four Ds' of energy system transformation – are being discussed to describe energy system change. Rather than existing as concrete facts, I argue that such trends are important analytical frames and highlight the role of their social construction in articulating and realising diverse energy futures. 266 unique instances of 'D' frames were found, involving actors from across multiple communities and from multiple geographies. Content analysis illustrates how articulations of energy trends has been used in actors' sense-making around the challenges, threats and opportunities presented by energy system change. I argue that many of these articulations can be understood in the context of increasing system complexity, and specifically, the need to rationalise technical, organisational and institutional logics of control. Given the apparent importance of the sociology of trends in shaping energy futures, the paper concludes by raising some provocations for research and policy.

Keywords

Decarbonisation, Decentralisation; Democratisation; Digitalisation; Trends; Transformation; Complexity

1 Introduction

Energy systems across the world are changing, not only in terms of the technologies involved, but also with respect to economic, social, geographic and political dimensions (1). For a variety of industry, policy and non-governmental actors, such changes represent significant shifts away from established norms. They disrupt traditional utilities whose business models are traditionally based on large-scale centralised thermal generation (2). They provide market entry points for new actors offering new value propositions, such as those around 'smart' energy products and services (3). In affecting flows across electricity networks, they present a variety of technical operational challenges to energy system operators (1). Lastly, these changes present considerable challenges to government actors responsible for managing energy transitions whilst regulating against negative impacts to consumers (4).

At the core of these challenges is the realisation that energy transitions are entering a new phase in which systems are becoming characterised by an increasingly diverse set of interacting actors and technologies, networked in increasingly dynamic ways, and resulting in the emergence of unpredictable outcomes (5). In other words, energy systems are in many ways becoming increasingly *complex* (6). Such complexity is at the root of new forms of uncertainty for decision makers across industry and government alike (6,7).

In an attempt to understand (and/or manage) processes of change, energy system actors are continuously engaged in analysis of energy futures, as well as the forces of change that are likely to affect these futures. In this regard, four key trends: decarbonisation, decentralisation, digitalisation

and democratisation are frequently mobilised to explain, discuss and challenge processes of change. Such trends may be understood as analytical frames (8,9) within which collections of knowledge, assumptions and worldviews about energy system change coalesce, and from which actors' interpretations and responses can be shaped.

Each of these trends have been examined in depth elsewhere. Briefly however, the *decarbonisation* of energy systems represents a major challenge for climate change mitigation of relevance across multiple scales of governance (10). Traditional reliance on large-scale centralised fossil-fuel based energy systems means that the concept of *decentralisation* has become a major focal point, capturing both trends in and normative goals around the restructuring of both physical and social infrastructures (11–15). More recently, *digitalisation* has emerged as a key trend with the potential to change norms in system operation, optimisation, consumer behaviour, industry and governance (16–20). Finally, the notion of energy *democratisation* has been discussed as a trend unfolding in parallel - and in response to – the aforementioned trends (21–26).

This research is motivated by an observation that these trends are frequently articulated in combination with each other, specifically by way of the 'three Ds' (decarbonisation, decentralisation and digitalisation) or 'four Ds' (to include democratisation) of energy system transformation. I hypothesise that the notion of the 'three Ds', 'four Ds' and other 'D frames' represent distinct analytical frames with which actors are making sense of the challenges and opportunities emerging from energy system change. To test this, I address three specific research questions. First, where and by whom are articulations about the three Ds and four Ds taking place? Second, what are the motivations for actors' articulations around the D frames? And third: what significance does actors' articulations of these trends in particular hold for sustainable energy transformations?

While the three Ds and four Ds have been used extensively among multiple actor communities, critical examination of the concepts is lacking. Even within academia, there has been a tendency to treat such trends as objective 'truths' (27,28) existing 'out there' as exogenous forces for actors to either respond to, or be disrupted by. In contrast, I argue here that it not is so much the trends themselves, but the sociology of trends, that requires attention as a key aspect of energy system change. Through the exploration of what has become something of a cliché or a buzzword among energy system actors, this work thus responds to calls for more critical examination of how energy futures are socially constructed (29–31).

After a brief discussion of the significance of trends *in general* for different groups of actors, I outline the sampling and analytical approach adopted. I then illustrate how the concept of the three Ds, four Ds and variations on the theme have proliferated across both geographical boundaries and actor communities, and examine the key themes emerging from actors' articulations of these trends. The penultimate section discusses the significance of these articulations for specific actor groups, and the final concluding section brings together some key findings, with implications for research and policy.

2 Trends within policy, industry and sustainability transitions

This research adopts the premise that decision making within energy systems is influenced by the ways in which actors understand and frame problems. In a broad sense, the treatment and management of 'problems' is a central theme within both energy policy and organisational strategy in terms of how policymakers, regulators and industry actors respond to outside pressures. Of particular relevance here is how actors deal with extraordinary problems that challenge established problem management procedures.

Three key theoretical perspectives on how actors identify and respond to such extraordinary problems – from organisational studies, political science and sustainability transitions – are summarised here. That these perspectives come from a range of disciplinary homes suggests that the management of exogenous problems hold relevance for scholars and practitioners working in and on the fields of policy, organisations and sustainability transitions.

2.1 Policy anomalies

First, decision making within policy environments can be understood to take place within *policy paradigms,* as frameworks of ideas about policy problems, goals and instruments shared by policymaking communities (32–34). While policy problems can frequently be dealt with within a given policy paradigm, that same policy paradigm can be challenged by the emergence of exogenous *policy anomalies*, or "developments that are not fully comprehensible, even as puzzles, within the terms of the paradigm" (34:280). In such cases, it may be necessary to modify the interpretive framework with which decisions are made (34,35).

Importantly, whether or not policy problems are deemed anomalous – and are therefore stressing existing policymaking processes - is open to interpretation. In other words, policy anomalies are 'informational signals' that must be interpreted by policymakers or regulators (36). For policy problems to be addressed, anomalies must be organised into coherent *narratives,* explaining why policy problems represent challenges to existing policy paradigms, and prescribing a credible alternative framework for dealing with them (36,37).

2.2 Trends and megatrends

Second, considerable attention has been given to how private organisations interpret and deal with exogenous change in the form of 'trends' within the strategic management literature. Here, trends have been conceptualised as 'weak signals', or warning signs, of discontinuities in the normal functioning of organisations (38). 'Megatrends' in turn are conceptualised as trends with pervasive, long-lasting and unpredictable impacts across society (39). The capacity of firms to identify and respond to trends and megatrends is crucial; they can represent 'strategic surprises', which can both threaten established value streams and create opportunities for new value streams (38,40).

With parallels with policy anomalies, megatrends do not exist 'out there' as concrete, objective warning signs for organisations. Rather, trends require interpretation by human actors (41), and articulation in the form of narratives to support and reinforce strategic management (42,43).

2.3 Landscape perturbations

These ideas align with a third set of parallel concepts from the literature on sustainability transitions. The Multi-Level Perspective (MLP) in particular suggests that innovation is dependent on – among other things - perturbations within an exogenous environment, termed the sociotechnical 'landscape' (44). The MLP understands sociotechnical transitions as the result of landscape level perturbations destabilising established sociotechnical regimes, and provide windows of opportunity for the adoption of niche innovations (44). Put another way, landscape perturbations create 'problems' for sociotechnical regimes which can only be solved through the modification of regime dimensions – technologies, markets, user practices, policies, and so on (45).

Once more though, exogenous shocks and stresses at the landscape level have no inherent meaning to system actors. Rather, meaning is constructed socially among regime actors, using narratives as interpretive vehicles of meaning to rationalise decision-making within regimes (46,47). Similarly, for

niche actors, narratives are important vehicles for legitimising innovations by articulating the *content* of innovations to the *contexts* in which they are seeking to find traction within (48,49).

While these three perspectives build on distinct academic foundations and take on distinct analytical focal points, three key observations with relevance to energy futures can be made. First, whether conceptualised as policy anomalies, megatrends, or landscape perturbations, it is evident that the tracking and management of exogenous trends for energy system actors matter. Second, energy trends do not exist 'out there' but are socially constructed, not least by those actors for whom such trends create problems. And third, it is through this social construction of trends that change (or indeed inertia) within policymaking, organisations or systems more broadly is rationalised.

The construction of energy trends can be placed in the broader context of 'energy futures' – an extension of the notion of social futures as "anticipatory discourses and techniques" used to visualise and elaborate the future(s)" (29,50). Through an examination of the rise of the three Ds and four Ds, this research responds to calls for more critical evaluation around how, by whom and with what implications energy futures are envisioned and enacted (29,51–56).

3 Methods

Content analysis (CA) is an established tool within the social sciences, allowing researchers to make valid inferences from text (57) by "objectively and systematically identifying specified characteristics of messages" (58, p.14). Such methods allow for quantitative and qualitative analysis of text in an objective and replicable manner (59). Enabling researchers to interrogate large volumes of data with relative ease (60), content analysis is of particular relevance in the context of the proliferation of textual, video and audio data available on the internet (61). CA is becoming increasingly well-established within energy studies, for example to examine articulations of energy services (59), to review references to physical science in social studies of energy (62), and to assess the nature and extent of social science in contemporary energy studies research (63).

This study uses CA to examine the nature and extent of adoption of D frames among energy system actors. This section outlines processes of sampling source data and coding for specific themes.

3.1 Search strategy

An original database of sources mentioning the D frames was constructed manually by the author between Oct 2019 and June 2020. In order to examine the diffusion of D frames from across the energy system as a whole (rather than from within academia), an explicit decision was made early in the process to include non-academic alongside academic sources.

Searches for academic sources were performed on the Scopus database, and non-academic sources were identified via Google searches. Searches were thus limited to searchable media published in some form on the internet, and while it is recognised that much strategic management occurs *within* organisations (64), the focus here is on the articulation of D frames in external communications.

Primary search terms included "energy AND 3Ds", "energy AND three Ds", "energy AND 4Ds" and "energy AND four Ds". In addition, "decarbonise AND decentralise AND digitalise" and "decarbonisation AND decentralisation AND digitalisation" (along with American English spelling variants of both) searches were included to capture instances where the terms "3D" or "4D" were not explicitly used, but where the focus was on still on articulating multiple, rather than individual trends. Searches were undertaken in English, limiting the dataset somewhat to those actors using English in communications. Searches continued until theoretical saturation was reached.

After removal of duplicates (e.g. duplicate blogs hosted on multiple sites), a corpus of 266 unique sources using D frames remained. Text from all sources was downloaded for analysis, and transcriptions of recorded interviews and presentations were downloaded and stored alongside media already in text form.

3.2 Coding strategy

Following bibliometric reviews undertaken elsewhere (e.g. 65), metadata within the dataset was collected to draw out patterns of diffusion of D frames. Dates of usage (publication date of report/website, or date of conference speech) were recorded to track the uptake of D frames over time. Geography by continent was identified to record the broad regions sources referred to, or else was recorded as 'Global' if there was no obvious reference to a specific jurisdiction or if sources referred explicitly to global trends. Finally, in order to understand the organisational context within which frames were used, instances were categorised into one of eight actor types: Incumbents, New entrants, Consultants, Industry intermediaries, Media, Academia, Policy/regulatory, and NGOs (e.g. charities, community energy groups and think tanks).

3.3 Thematic analysis

Coding was undertaken in NVivo by a single coder in two stages. In the first stage, emergent coding (61) was employed in which references to D frames were found within source documents, and the surrounding text was examined to identify themes relating to the overall context in which the D frames were being employed. In particular, these themes related to the degree to which trends were used as sense-making devices, and in particular, whether D frames are understood as exogenous forces or normatively positive, with subjective interpretation used to code sources throughout. The sources mentioning these themes were summed to assess the prevalence of these themes across the whole dataset.

The second stage drew on two broad themes identified in stage 1 to explore the detail in which key actors articulated a) explanations of, and b) responses to, D frames. These articulations were termed 'descriptions' (i.e. what the 3Ds mean) and 'prescriptions' (i.e. how to respond to the 3Ds). Analysis in this stage focused on a subset of three groups of actors - Incumbents, Policy and regulatory actors and NGOs, selected on the basis that these groups represent distinct organisational cultures and who were deemed likely to interpret energy system change in distinct ways. This represented a subset of 102 sources, a list of which can be found in Appendix A. Any sources not engaging with descriptions and/or prescriptions explicitly were excluded from this part of the analysis. These sources were coded under the broad theme of complexity, and in particular, system interconnectedness, emergent outcomes, and ideas of control (or lack thereof). Quotations from selected sources were identified to provide supplemental context for the results.

4 How have D frames diffused over time?

This section seeks address the first research question, namely: where and by whom are articulations around the three Ds and four Ds taking place?

4.1 Competing D frames

Up until June 2020, 266 unique instances of the use of D frames were found. Most of these (n=190) referred to the three Ds (decarbonisation, decentralisation and digitalisation) with a significant number (n=38) referring to four Ds (three Ds plus democratisation). A third set of sources (n=38) referred to multiple other combinations of trends, most of which begin with the letter 'D'. These with more than one reference include 'Deregulation' (n=6), changes to 'Demand' (4), 'Diversification'

(4), 'Disruption' (3), 'Demonstration' (3), Electrification (2), Demography (2) and Dynamic regulation (2).

The emergence evolution of variants of D frames over time may in part be explained in terms of the memetic qualities of the frames (66). That the majority of variants start with a 'D' suggests that the mnemonic quality of the frames is part of the appeal, and that it is the broad notion of 'the 3Ds' that is of value, rather than the detail of the concepts therein, particularly as it makes the term easy to remember (or misremember) and readily communicated.

However, like memes more generally, D frames are evidently prone to mutation, and are tailored to suit specific interpretations of local challenges. 'Demonstration' for example is used in the context of community energy to highlight the importance of energy activism (67), while 'Demographic change' is used to discuss population growth and urbanisation in Africa (68). Also of note is the fluidity of meaning ascribed to specific terms. Particular ambiguity is evident in the variety of meanings given to decentralisation and democratisation, a point echoed in the literature on these terms (12,21,22).

4.2 The diffusion of D frames among actors

An increasing number and diversity of actors used D frames to articulate energy trends up until 2020, with usage of the terms slowing thereafter (Figure 1a). The earliest recorded instances of D frames being used explicitly is in 2009 and 2014, both to characterise community energy projects by their ability to decarbonise and Decentralise energy supplies, Democratise governance, and Demonstrate the effectiveness of renewable energy and novel ownership models, rather than to describe broader energy trends as such (67,69). Thereafter, D frames were adopted by specific industry organisations (most notably Engie) and NGOs in 2015 before being adopted by a diversity of actor types. The data suggests a drop-off in the use of D frames in the first half of 2020, although since data was only collected up to mid-2020 it is unclear whether uses continued to plateau beyond then.

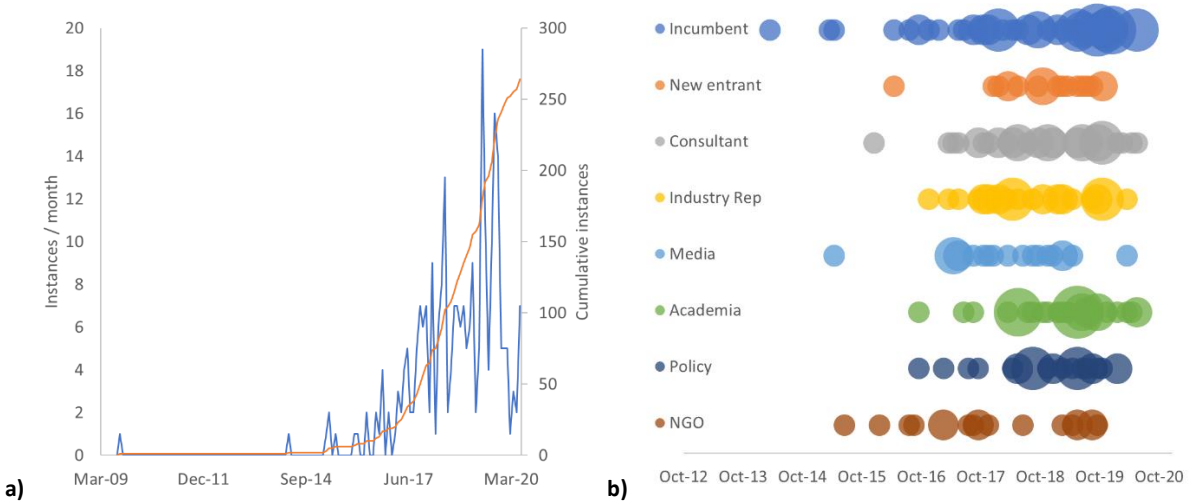


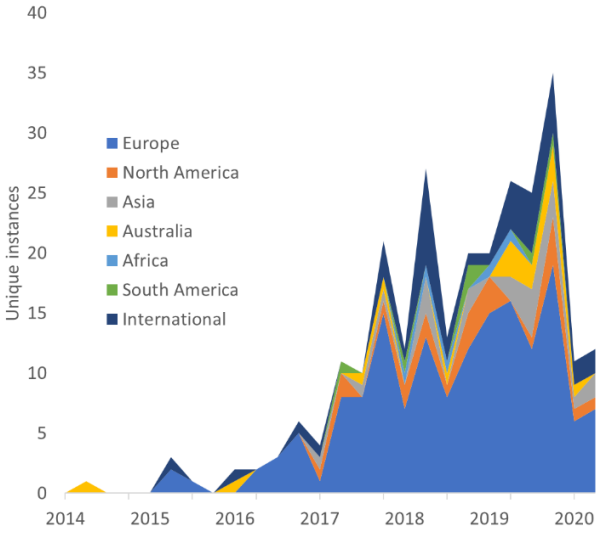
Figure 1. a) Growth in the use of D frames over time and b) adoption by different actor types
Note. The area of bubbles in 1b is proportional to the number of sources in a given month.

Of note is the diversity of energy system actors for whom three D and four D frames apparently hold resonance. All actor types have actively contributed to the development of D frame discourses although incumbent firms make up the majority of contributions (27%). Several large actors (Engie, Siemens, and National Grid) stand out as repeated users of three D frames (n=14, 8, and 7 instances respectively), deploying them across multiple channels (e.g. reports, websites, trade conferences)

and across multiple jurisdictions. That incumbent industry actors appear to be making efforts to forge ideas about energy system change is perhaps unsurprising given the potential existential threat to existing business models, and – when compared to other actor types, the organisational resources available. Consultants, industry bodies and media organisations together represent another large set of contributions (35%). Again, this is not surprising given that the business models of these actors generally centre on reflecting prevailing trends and represent industry interests.

4.3 D frames across geographies

Geographically, use of the framings has been concentrated in Europe (in part a reflection of searches being undertaken in English), although instances have been found in Asia, Africa and North and South America (Figure 3). This suggests that these trends are either more profound in OECD countries, and/or that analysts from the global south are less engaged with these specific framings of energy system change. Another explanation is that 3D/4D frames have simply found most traction in English speaking countries because of the alliterative quality of decarbonisation, decentralisation and digitalisation and democratisation, strengthening its effectiveness as a meme.



That D frames have been adopted by actors operating within multiple energy systems suggests that trends relating to decarbonisation, decentralisation, digitalisation and democratisation resonates among a global ecosystem of actors operating across a multiplicity of jurisdictions. It is noted that many energy utilities, consultancies and media firms are multinational corporations, meaning that ideas, human resources and organisational strategy are not confined to specific energy systems. For example, Engie, Schneider, Siemens and Tata are all recorded as using D frames in relation to multiple jurisdictions. Even when actors do not operate across multiple jurisdictions, the internet and the use of English as a lingua franca has meant that ideas relating to energy system change have been able to transfer readily across different geographies. As is the case with physical energy resources and infrastructure (70), this suggests that energy discourses too are spatially complex, with ideas and narratives flowing readily across system boundaries.

In summary, the articulation and communication of energy system trends appears to be an active process taking place among a diversity of actor communities. In short, energy trends evidently *matter*. The examination of the invention, diffusion and normalisation of energy trends presented here supports the characterisation of trends as socio-cultural innovations in themselves (71). Through an exploration of how trends are interpreted within actor communities, the next section seeks to critically examine the social construction of trends.

5 What do actors talk about when they talk about D frames?

This section seeks to address the second research question: what are the motivations for actors' articulations around the three Ds and four Ds?

5.1 Sense-making

A key set of themes emerging from the dataset relate to sense-making, described by Rutledge as "a "communication process through which groups make sense of events and circumstances that affect them" (72). Specifically, actors are using D frames to describe how energy systems are changing, explaining variously what this means for themselves and/or the energy system as a whole.

An overview of the ways in which different actor types described D frames is summarised in Table 1. For the majority of those surveyed, D frames appear to exist primarily as exogenous forces. These actors tended to discuss three D / four D trends as happening 'out there', beyond their direct influence, but shaping the contexts within which they operate.

Table 1. Broad understandings of D frames by different actor types

		D frames as:		
		Exogenous	Beneficial trends	Normative ideals
Actor type	Incumbents (n=65)	54	9	0
	New entrants (n=14)	9	4	1
	Consultants (n=35)	26	5	4
	Industry Representatives (n=20)	14	3	3
	Media (n=15)	12	1	2
	Academia (n=27)	19	5	4
	Policy (n=23)	17	4	2
	NGO (n=19)	9	5	4

At the other end of the spectrum is a much smaller proportion of actors articulating D frames primarily as normative ideals around what energy systems *ought to* look like. As a proportion of the total number of sources for each actor type, normative frames were most common among NGOs and new entrants, perhaps reflecting a desire to shape (rather than be shaped by) energy systems. A third set of actors appear to understand trends as exogenous, while also emphasising that the trends, or at least some aspects of them, are normatively desirable. These actors thus articulated D frames as 'beneficial trends' which while driven primarily by external forces, can also be supported by the actors in question.

The individual trends of decarbonisation, decentralisation and democratisation all have normative dimensions, so it is not surprising that normative interpretations are also embedded across these broader D frames. It is also important to note how these concepts frequently bleed into one another. For some actors, the distribution of energy assets across a greater diversity of prosumers is encapsulated within the concept of 'decentralisation', whereas other actors articulate similar processes in terms of 'democratisation'. In short, while many actors are engaged in sense making, the motivations for doing so appears to vary between actor types.

5.2 Descriptions of complexity

A second set of themes emerging from the data relate to increasing system complexity. As already mentioned, energy system complexity arises from the incorporation of an increasingly diverse set of

interacting actors and technologies, whose dynamic interconnections give rise to emergent and unpredictable outcomes (5). Descriptions of a) system interconnectedness and b) emergent outcomes both featured strongly in actors' articulations of D frames.

Actors from all sectors emphasised how the incorporation of increasing number and diversity of electricity demand, generation and storage technologies into energy systems is changing the nature of supply and demand. Together with 'prosumers' as new human 'components', these technological components are also increasingly coupled, potentially resulting in increasingly dynamic energy flows.

Articulations of the drivers of complexity thus commonly appear in conjunction with discussions of the emergent outcomes arising from increasing interconnectedness. In particular, actors highlight operational challenges associated with balancing increasingly complex energy systems, as well as the organisational challenges – and opportunities – new energy systems present. Such explicit articulations appear to be important in helping actors to rationalise and frame organisational responses.

Finally, actors rarely discussed decarbonisation, decentralisation, digitalisation and democratisation as isolated trends, but rather as interconnected in dynamic, non-linear ways. For example, digitalisation is regarded by actors employing D frames as a key enabler of energy system decentralisation through the adoption of smart home technologies and services; meanwhile however, decentralisation will *require* ongoing digitalisation of energy systems, for example to help balance supply and demand.

As such, D frames frequently capture the interconnectedness not only of energy system components, but of the trends themselves. Such dynamics act to enhance the strength of broader D frame narratives, in that the credibility of each of the trends relies on that of other trends (73). In-depth analysis of decarbonisation as a trend, for example, requires consideration of decentralisation and digitalisation. In sum, the dynamic feedback mechanisms arising within – but also between – the trends of decarbonisation, decentralisation, digitalisation and democratisation give rise to perceptions of increasing system complexity.

5.3 Prescriptions for complexity

As well as being used to *describe* ongoing trends, actors also use D frames to *prescribe* responses to the challenges of increased complexity. Broadly, these responses fall into two distinct logics of control: technological and institutional responses.

All groups of actors, but incumbents in particular - suggested that the technological and operational challenges emerging from increased system complexity are to varying extents, control challenges that can be solved by technological innovation. Digitalisation in particular, i.e. the introduction of digital hardware and software – represents a specific set of control innovations that are deemed necessary to address the challenges brought about by decarbonisation/decentralisation, particularly to help integrate and optimise increasing amounts of intermittent generation. As well as proposing technologies, actors highlight the importance of 'whole system' solutions for decarbonisation, such as the integrating of heat and transport technologies within electricity networks.

For a small number of actors, gas (both fossil-based and 'green' gas) technologies are presented as necessary responses to decarbonisation and decentralisation challenges. ETN, a Brussels-based gas turbine membership organisation state that "Despite the renewable boom, it is foreseen (e.g. by the International Energy Agency (IEA)) that conventional gas-fired power generation, currently the largest gas-consuming sector worldwide, will continue to play a strategic role" (74). Statements such

as this highlight both how malleable D frames can be, and illustrates the potential for actors to take advantage of that flexibility in an effort to legitimise unsustainable energy pathways (29).

In terms of institutional responses, the need for new business models emerged as a common theme across multiple actor types, although with divergent sentiments behind these articulations. For a very small number of incumbents, this takes the form of reflexive examination of the ability to keep up with shifting value streams in order to control one's own future. Gérard Mestrallet, CEO of Engie marked the creation of Engie from GDF Suez in 2015 with the statement that "The energy transition is more than ever a reality for which we have both great ambitions and a great responsibility. To meet the new challenges of this reality and to accelerate our development, we have decided to give the Group a new name: ENGIE" (75).

Despite the inevitable disruption to incumbent firms (67) however, it is striking that – in contrast to the quote above - most incumbents are ostensibly unperturbed about disruption to their own business models, at least within the dataset. This may be a function of the analytical frame, i.e. it may well be that organisations are inwardly much more reflexive than these outward-facing articulations suggest. However, analysis from elsewhere suggests that incumbent firms have been limited in their responses to disruption caused by decarbonisation and digitalisation (27).

For NGO and policy/regulatory actors, institutional responses focused on the democratising potential of new business models to empower energy citizens, and on the need for regulation to control for the protection of consumers against emergent (negative) outcomes of system change (76).

6 Discussion

What significance does actors' articulations of these trends hold for sustainable energy transformations? To address this third research question, this section explores the relevance of complexity for energy system actors, and offers reflections on the implications of sense-making for the creation of energy futures.

6.1 Learning to dance with complexity?

Faced with systemic uncertainty, the key challenge for all actors may be to acknowledge the limits of control in increasingly complex energy systems, and to learn to embrace or (as the complexity theorist Donella Meadows would suggest) to 'dance' with complexity (77). In brief, dancing with complexity represents a different sort of 'doing', which accepts unpredictability as a natural function of complex systems, and acting accordingly in the context of unpredictability. What does this mean for energy system actors and institutional cultures across industry, policymaking and regulation?

Energy firms – and incumbent firms in particular – are evidently engaged in making sense of complexity. The process of sense making in general is thought to be important in orienting action (78), although the data explored here suggests that there are multiple possible responses being prescribed to complexity. First, as is the case with megatrends more generally, D frames might be understood as 'empty signifiers' (79) within which key themes can be emphasised to suit specific actors' storylines. This can be seen in gas turbine manufacturers' storylines situating dispatchable gas as solutions to the unpredictability that comes with increasing amounts of intermittent generation.

On the other hand, other incumbent firms appear to be confronting the challenges presented by complexity in more profound ways. For example, Engie's articulations about the changing state of energy systems appears to underpin organisational reflexivity around innovation cultures in the firm.

In the words of Engie's Marc Florette in 2015: "We are a large company but the world is complex and we cannot pretend to have all the good ideas." (80). Such statements mark shifts – among some firms at least - towards more agile forms of 'open innovation' whereby risk and reward is dispersed across a network of collaborators with a view to opening up strategic horizons to new value streams (81).

Similarly, for policymakers and regulators, whose actions govern the feedback mechanisms that characterise complex systems, acknowledging and adapting to increased system complexity is critical. The need for policymakers to be more adaptive has been explored elsewhere, not least in the literature on decision making under deep uncertainty (82,83). In this sense, the system complexity arising from combined energy system trends can be understood as a policy anomaly in its own right, which requires reflexivity around the cultures and frameworks of regulation, and a renewed focus on agility and proactivity in policymaking.

While dancing with complexity however, policymakers and regulators are also charged with managing the speed and direction of energy system change and associated social, economic and environmental outcomes. Herein lies a central challenge for policy and regulatory actors – how to establish coherent policy mixes or electricity markets that provide stability and certainty, but which also provides an enabling environment for accelerated change and the inevitable instability acceleration brings (84–86).

6.2 Sense-making and energy futures

This analysis of D frames suggests that sense-making in the context of increasing system complexity has become an important undertaking for energy system actors of all kinds. This sense making can be understood in relation to the articulation of energy futures, or more precisely, articulations of actor's positions in energy futures. More specifically, D frame articulations represent elaborations by organisations about what aspects of energy system change are 'problematic', and in what ways organisations should respond.

As with both policy problems and sense making within organisations (78,87), the very process of articulating energy system trends can be expected to shape if and how organisations choose to deal with trends. In broad terms, organisations can articulate problems as exogenous issues to be dealt with, or else exogenous issues that are compounded by problems within the organisations themselves.

It is perhaps inevitable that the lion's share of sense-making by way of articulation of D frames is taking place by incumbent actors. These actors not only have the most financial, political and organisational resources available to deploy, but have the most to lose from sectoral disruption (88). As such, efforts to steer trends, as well as the broader social construction of trends towards futures that favour their own interests can be expected (89). As Stoddard et al (29) assert, "the making of energy futures remains an elite activity that is driven by corporate and government leadership and oriented around changes to policy, economic markets, and energy technologies".

In this sense, it is important to remain critical of the ways in which energy trends such as those encapsulated in D frames are discussed. Understanding trends as purely objective economic patterns not only backgrounds the importance of the social construction of patterns, but ignores the agency of actors in shaping energy futures and therefore energy pathways.

6.3 Significance and limitations

In focusing on the articulation of trends within organisations, this research is considered to be generalizable across other contexts and time periods. The framework and methods employed here could readily be adapted to examine other broad trends within and beyond the theme of energy system transformations. While not used here, the proliferation of digital media of different kinds lends itself to automated textual analysis of extremely large corpuses (90), which no doubt present distinct methodological challenges alongside the potential for the development of valuable insights.

Several limitations of this research can be highlighted. In terms of the sampling strategy, efforts were made to incorporate a broad cross section of sources mentioning D frames. Consequently, the sample varied considerably in terms of whether D frames constituted a central element of sources, or whether they were mentioned in passing as pieces of context. Focusing only on sources that discussed the relevance of D frames in explicit terms may have affected the analysis. However, the intention here was to capture a broad range of sources to identify general patterns in uptake and articulations, rather, for example, examine articulations by organisations on an individual basis. It is acknowledged that focusing on English language sources will have skewed the sample towards the global north, and although it is expected that some of this effect might have been balanced by the prevalence of English as a lingua franca. Since coding was undertaken by a single coder, it is conceivable that a second coder could have allowed a different set of themes to emerge, or offered a different interpretation of these themes, although this risk is offset somewhat by the subjective consistency offered by a single coder.

7 Conclusions and implications for research and policy

This paper set out to understand the patterns, motivations and significance of actors' articulations of the combined trends of decarbonisation, decentralisation, digitalisation and democratisation and associated analytical frames. It presents results of content analysis (CA) of a wide range of sources mentioning these frames, spanning both academic and grey literatures.

This research has highlighted how D frames have propagated across both geographies and the energy system actor communities therein, demonstrating the broad relevance of ideas and narratives about energy system trends across jurisdictions. One factor driving this propagation is the inherent ambiguity of the concept of the 'three Ds' (as well as the individual trends therein), as it gives actors space to actively lend their own interpretations about these trends in response to local issues, threats and opportunities while ostensibly adopting the terms already in use by energy system actors.

In terms of the motivations for articulating D frames, I suggest that actors have only recently become actively engaged in sense-making about the multitude of changes taking place in energy systems, and the implications for their own roles and responsibilities. Themes of existential and systemic threats and opportunities are relatively common within actor's articulations. However, this analysis suggests that very few organisations appear to be actively (or at least outwardly) engaged in reflexivity.

It is the intention that this perspective provokes further discussion on the use and analysis of trends such as those encapsulated in the four Ds. I stop short of suggesting that uptake of the four Ds is indicative of a universal paradigm shift. The four Ds evidently mean many things to many actors. One perspective is that the four Ds is something of a cliché or a buzzword, whose appeal may simply be a function of its pleasing alliterative structure and its memorability as a mnemonic.

However, I suggest here that the ways in which actors are employing the concept of the three/four Ds deserves further attention, and offer three specific provocations in the hope of stimulating discussion within research and policymaking communities.

First, which direction of causality is more important here? It is often taken for granted that organisations respond to trends happening 'out there' (91) but it is also entirely plausible that actors' articulation of trends affects the shape and intensity of such trends (73). It is logical, for example, to imagine that energy digitalisation will be determined by, among other things, organisational interpretations of what digitalisation should look like, rather than what digitalisation might achieve under 'ideal' conditions (19). This raises questions about the degree to which individual actors, events and articulations might influence trend discourses more broadly.

Second, a central theme of this paper is that the sociology of trends matter, at least as much as the trends themselves. However, the degree to which the understanding of trends within organisations shape strategic decisions is unclear. For example, how do cultures of 'trend management' within organisations interact with power and political interests within and among organisations? Such questions raise the potential for research opportunities that bring together insights from organisational studies with those from sustainability transitions to understand more about the ways in which trends are understood, propagated and managed within organisations and communities thereof.

Finally, how can a greater diversity of actors more actively challenge prevailing trends or even act to catalyse the social construction of new trends? If we accept that 1) trends are socially constructed, and 2) that trends 'matter' in shaping the contexts within which actors respond, then the degree to which energy system trends – decarbonisation, decentralisation, digitalisation and democratisation – align with normative goals around sustainable energy futures, needs to be examined. At the very least, it seems important to ensure that civil society becomes active in understanding and articulating such trends, and their implications for sustainable energy futures. Similarly, there is a strong case for governments, rather than just private firms, to display thought leadership around what kind of energy future we, collectively, wish to articulate and realise.

Declaration of Competing Interest

The author declares that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The author would like to thank Jess Britton for her valuable comments on an early iteration of this paper, two anonymous reviewers for their comments and suggestions to improve this manuscript, and Benjamin Sovacool for his ongoing guidance and support.

Funding

This work was supported by the Engineering and Physical Sciences Research Council (EPSRC) [EP/K001582/1].

References

1. Mitchell C. Momentum is increasing towards a flexible electricity system based on renewables. Nat Energy. 2016;1:15030.

2. Richter M. Business model innovation for sustainable energy: German utilities and renewable

energy. Energy Policy. 2013;62:1226–37.

3. Hall S, Roelich K. Local Electricity Supply: Opportunities, archetypes and outcomes. Energy Policy. 2015;92:286–98.

4. Kuzemko C, Lockwood M, Mitchell C, Hoggett R. Governing for sustainable energy system change: Politics, contexts and contingency. Energy Res Soc Sci. 2016;12:96–105.

5. Markard J. The next phase of the energy transition and its implications for research and policy. Nat Energy. 2018;3(8):628–33.

6. Bale CSE, Varga L, Foxon TJ. Energy and complexity: New ways forward. Appl Energy. 2015;138:150–9.

7. Stanton MCB, Roelich K. Decision making under deep uncertainties: A review of the applicability of methods in practice. Technol Forecast Soc Change. 2021 Oct 1;171:120939.

8. Sanderink L. Shattered frames in global energy governance: Exploring fragmented interpretations among renewable energy institutions. Energy Res Soc Sci. 2020;61:101355.

9. Fisher K. Locating Frames in the Discursive Universe. Sociol Res Online. 1997 Sep;2(3):88–111.

10. IPCC. Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change,. Masson-Delmotte V, Zhai P, Pörtner HO, Roberts D, Skea J, P.R.Shukla, et al., editors. 2018.

11. Goldthau A. Rethinking the governance of energy infrastructure: Scale, decentralization and polycentrism. Energy Res Soc Sci. 2014;1:134–40.

12. Judson E, Fitch-Roy O, Pownall T, Bray R, Poulter H, Soutar I, et al. The centre cannot (always) hold: Examining pathways towards energy system de-centralisation. Renew Sustain Energy Rev. 2020;118:109499.

13. Alstone P, Gershenson D, Kammen DM. Decentralized energy systems for clean electricity access. Nat Clim Chang. 2015;5(4):305–14.

14. Berka A, Dreyfus M. Decentralisation and inclusivity in the energy sector: Preconditions, impacts and avenues for further research. Vol. 138, Renewable and Sustainable Energy Reviews. Elsevier Ltd; 2021. p. 110663.

15. Brisbois MC. Shifting political power in an era of electricity decentralization: Rescaling, reorganization and battles for influence. Environ Innov Soc Transitions. 2020 Sep 1;36:49–69.

16. Küfeoglu S, Liu G, Anaya K, Pollitt M. Digitalisation and New Business Models in Energy Sector. EPRG Working Paper 1920. 2019.

17. Rhodes A. Digitalisation of Energy. Energy Futures Lab Briefing Paper. 2020.

18. Sovacool BK, Furszyfer Del Rio DD. Smart home technologies in Europe: A critical review of concepts, benefits, risks and policies. Renew Sustain Energy Rev. 2020;120(May 2019):109663.

19. Judson E, Soutar I, Mitchell C. Governance Challenges Emerging from Energy Digitalisation. EPG Discussion Paper EPG2002. 2020.

20. Hansen P, Morrison GM, Zaman A, Liu X. Smart technology needs smarter management: Disentangling the dynamics of digitalism in the governance of shared solar energy in Australia. Energy Res Soc Sci. 2020;60(October 2019):101322.

21. Szulecki K. Conceptualizing energy democracy. Env Polit. 2018;27(1):21–41.

22. van Veelen B, van der Horst D. What is energy democracy? Connecting social science energy research and political theory. Energy Res Soc Sci. 2018;46:19–28.

23. Szulecki K, Overland I. Energy democracy and its limits: Is energy democracy a process, an outcome, or a goal? Energy Polit Policy Gov. 2020;

24. Burke MJ, Stephens JC. Energy democracy: Goals and policy instruments for sociotechnical transitions. Energy Res Soc Sci. 2017;33(September):35–48.

25. Morris C, Jungjohann A. Energy Democracy: Germany's Energiewende to Renewables [Internet]. Springer. 2016 [cited 2020 Jul 24]. 437 p. Available from: https://link.springer.com/content/pdf/10.1007/978-3-319-31891-2.pdf

26. Becker S, Naumann M. Energy democracy: Mapping the debate on energy alternatives. Geogr Compass. 2017;11(8):1–13.

27. Kattirtzi M, Ketsopoulou I, Watson J. Incumbents in transition? The role of the 'Big Six' energy companies in the UK. Energy Policy. 2021 Jan 1;148:111927.

28. Di Silvestre ML, Favuzza S, Riva Sanseverino E, Zizzo G. How Decarbonization, Digitalization and Decentralization are changing key power infrastructures. Vol. 93, Renewable and Sustainable Energy Reviews. Elsevier Ltd; 2018. p. 483–98.

29. Stoddart MCJ, McCurdy P, Slawinski N, Collins CG. Envisioning energy futures in the North Atlantic oil industry: Avoidance, persistence, and transformation as responses to climate change. Energy Res Soc Sci. 2020;69:101662.

30. Jasanoff S. Just transitions: A humble approach to global energy futures. Energy Res Soc Sci. 2018;35(December 2017):11–4.

31. Nilsson M, Nilsson LJ, Hildingsson R, Stripple J, Eikeland PO. The missing link: Bringing institutions and politics into energy future studies. Futures. 2011;43(10):1117–28.

32. Baumgartner FR. Ideas and Policy Change. Governance. 2013;26(2):239–58.

33. Carson M. From Common Market to Social Europe?: Paradigm Shift and Institutional Change in European Union Policy on Food, Asbestos and Chemicals, and Gender Equality. Stockholm; 2004.

34. Hall PA. Policy Paradigms, Social Learning, and the State: The Case of Economic Policymaking in Britain. Comp Polit. 1993 Apr;25(3):275.

35. Sabatier P. An Advocacy Coalition Framework of Policy Change and the Role of Policy-Oriented Learning Therein. Policy Sci. 1988;21(2/3):129–68.

36. Wilder M, Howlett M. Paradigm Construction and the Politics of Policy Anomalies. In: Hogan J, Howlett M, editors. Policy Paradigms in Theory and Practice Discourses, Ideas and Anomalies in Public Policy Dynamics. London: Palgrave Macmillan; 2015.

37. Kern F, Kuzemko C, Mitchell C. Measuring and explaining policy paradigm change: the case of UK energy policy. Policy Polit. 2014;

38. Ansoff HI. Managing strategic surprise by response to weak signals. Calif Manage Rev. 1975;18(2):21–33.

39. Vejlgaard H. Anatomy of a Trend. McGraw-Hill New York; 2008.

40. Rossel P. Weak signals as a flexible framing space for enhanced management and decision-making. Technol Anal Strateg Manag. 2009;21(3):307–20.

41. Seidl D, Tsoukas H, Shepherd J. The concept of weak signals revisited: a re-description from a constructivist perspective. Manag Futur foresight Knowl Econ. 2004;151–68.

42. Barry J, Ellis G, Robinson C. Cool rationalities and hot air: a rhetorical approach to understanding debates on renewable energy. Glob Environ Polit. 2008;8(2):67–98.

43. Phillips N, Sewell G, Jaynes S. Applying Critical Discourse Analysis in Strategic Management Research. journals.sagepub.com. 2008 Oct;11(4):770–89.

44. Geels F. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. Res Policy. 2002;31(8):1257–74.

45. Geels F, Schot J. Typology of sociotechnical transition pathways. Res Policy. 2007;36(3):399–417.

46. Westerhoff L, Robinson J. Practicing' narratives: Exploring the meaning and materiality of climate change. In: Transformation in a changing climate. 2013.

47. Hermwille L. The role of narratives in socio-technical transitions - Fukushima and the energy regimes of Japan, Germany, and the United Kingdom. Energy Res Soc Sci. 2016 Jan 1;11:237–46.

48. Smith A, Kern F, Raven R, Verhees B. Spaces for sustainable innovation: Solar photovoltaic electricity in the UK. Technol Forecast Soc Change. 2014;81(0):115–30.

49. Rosenbloom D, Berton H, Meadowcroft J. Framing the sun: A discursive approach to understanding multi-dimensional interactions within socio-technical transitions through the case of solar electricity in Ontario, Canada. Res Policy. 2016 Jul 1;45(6):1275–90.

50. Urry J. What is the future? Wiley; 2016. 200 p.

51. Jasanoff S, Kim S-H. Sociotechnical imaginaries and national energy policies. Sci Cult (Lond). 2013;22(2):189–96.

52. Hajer MA, Pelzer P. 2050—An Energetic Odyssey: Understanding 'Techniques of Futuring' in the transition towards renewable energy. Energy Res Soc Sci. 2018;44(July 2017):222–31.

53. Delina L, Janetos A. Cosmopolitan, dynamic, and contested energy futures: Navigating the pluralities and polarities in the energy systems of tomorrow. Energy Res Soc Sci. 2018;35:1–10.

54. Soutar I, Mitchell C. Towards pragmatic narratives of societal engagement in the UK energy system. Energy Res Soc Sci. 2018;35:132–9.

55. Chilvers J, Pallett H, Hargreaves T. Ecologies of participation in socio-technical change: The case of energy system transitions. Energy Res Soc Sci. 2018;42(April):199–210.

56. Mey F, Diesendorf M. Who owns an energy transition? Strategic action fields and community wind energy in Denmark. Energy Res Soc Sci. 2018;35(March 2017):108–17.

57. Weber RP. Basic Content Analysis. London: SAGE; 1990. 96 p.

58. Holsti OR. Content Analysis for the Social Sciences and Humanities. Reading, MA: Addison-Wesley;

59. Fell MJ. Energy services: A conceptual review. Energy Res Soc Sci. 2017 May 1;27:129–40.

60. Krippendorff K. Content Analysis: An Introduction to Its Methodology. London: SAGE Publications, Inc; 2018. 472 p.

61. Stemler SE. Content Analysis. In: Emerging Trends in the Social and Behavioral Sciences. Wiley; 2015. p. 1–14.

62. Cooper ACG. Building physics into the social: Enhancing the policy impact of energy studies and energy social science research. Energy Res Soc Sci. 2017 Apr 1;26:80–6.

63. Sovacool BK. What are we doing here? Analyzing fifteen years of energy scholarship and proposing a social science research agenda. Energy Res Soc Sci. 2014;1:1–29.

64. Gioia DA, Chittipeddi K. Change Initiation. Strateg Manag J. 1991;12:433–48.

65. Gaede J, Rowlands IH. Visualizing social acceptance research: A bibliometric review of the social acceptance literature for energy technology and fuels. Vol. 40, Energy Research and Social Science. Elsevier Ltd; 2018. p. 142–58.

66. Dawkins R. The Selfish Gene. Oxford Paperbacks; 1976.

67. Ison N. Overcoming technical knowledge barriers to community energy projects in Australia. BEng dissertation [Internet]. School of Civil and Environmental Engineering. University of New South Wales; 2009. Available from: http://www.cpagency.org.au/files/NickyIsonCommunityEnergy.pdf

68. Aggreko. Positioned for growth in a changing energy market. Aggreko plc Annual Report and Accounts 2019. 2019.

69. Hicks J, Ison N, Gilding J, Mey F. Community-owned renewable energy: A how-to guide [Internet]. Community Power Agency; 2014. Available from: https://www.environment.nsw.gov.au/resources/communities/cpa-community-energy-how-to.pdf

70. Binz C, Truffer B. Global Innovation Systems—A conceptual framework for innovation dynamics in transnational contexts. Res Policy. 2017;46(7):1284–98.

71. Liebl F, Schwarz JO. Normality of the future: Trend diagnosis for strategic foresight. Futures. 2010;42(4):313–27.

72. Rutledge M. Sensemaking as a tool in working with complexity. OD Pract. 2009;41(2):19–24.

73. Shiller R. Narrative Economics. Princeton NJ, editor. Princeton University Press;

74. ETN Global. Gas Turbines: Important Conversion Technology For The Future [Internet]. 2018 [cited 2021 Jul 23]. Available from: https://etn.global/about-etn/gas-turbine-technology/about-gas-turbines/

75. Engie. GDF Suez is now Engie [Internet]. 2015 [cited 2019 Jun 12]. Available from: https://www.engie.com/en/#home

76. Voss J-P, Bauknecht D, R. Kemp. Reflexive Governance for Sustainable Development. Edward Elgar Publishing; 2006.

77. Meadows DH. Thinking in systems: A primer. chelsea green publishing; 2008.

78. Weick KE, Sutcliffe KM, Obstfeld D. Organizing and the Process of Sensemaking. Organ Sci. 2005;16(4):409–21.

79. Von Groddeck V, Schwarz JO. Perceiving megatrends as empty signifiers: A discourse-

theoretical interpretation of trend management. Futures. 2013;47:28–37.

80. PWC. Digital utility transformation [Internet]. 2015 [cited 2021 Jul 23]. p. 16. Available from: https://www.pwc.com/gx/en/utilities/publications/assets/pwc-digital-utility-transformation.pdf

81. Curley M, Salmelin B. Open Innovation 2.0: The New Mode of Digital Innovation for Prosperity and Sustainability. Cham, Switzerland: Springer; 2018.

82. Walker W, Haasnoot M, Kwakkel J. Adapt or Perish: A Review of Planning Approaches for Adaptation under Deep Uncertainty. Sustainability. 2013 Mar 4;5(3):955–79.

83. Roelich K, Giesekam J. Decision making under uncertainty in climate change mitigation: introducing multiple actor motivations, agency and influence. Clim Policy. 2019 Feb 7;19(2):175–88.

84. Ford R, Hardy J. Are we seeing clearly? The need for aligned vision and supporting strategies to deliver net-zero electricity systems. Energy Policy. 2020 Dec 1;147:111902.

85. Victor DG, Geels FW, Sharpe S. Accelerating the low carbon transition: The case for stronger, more targeted and coordinated international action [Internet]. 2019. Available from: https://www.brookings.edu/wp-content/uploads/2019/12/Coordinatedactionreport.pdf

86. Roberts C, Geels FW, Lockwood M, Newell P, Schmitz H, Turnheim B, et al. The politics of accelerating low-carbon transitions: towards a new research agenda. Energy Res Soc Sci. 2018;44:304–6296.

87. Feindt PH, Oels A. Does discourse matter? Discourse analysis in environmental policy making. Vol. 7, Journal of Environmental Policy and Planning. Routledge; 2005. p. 161–73.

88. Seto KC, Davis SJ, Mitchell RB, Stokes EC, Unruh G, Ürge-Vorsatz D. Carbon Lock-In: Types, Causes, and Policy Implications. Annu Rev Environ Resour. 2016;41:425–52.

89. Jacobsson S, Lauber V. The politics and policy of energy system transformation—explaining the German diffusion of renewable energy technology. Energy Policy. 2006;34(3):256–76.

90. Rheault L, Beelen K, Cochrane C, Hirst G. Measuring emotion in parliamentary debates with automated textual analysis. PLoS One. 2016;11(12):1–18.

91. Bergek A, Berggren C, Magnusson T, Hobday M. Technological discontinuities and the challenge for incumbent firms: Destruction, disruption or creative accumulation? Res Policy. 2013;42(6–7):1210–24.