Climate Change Assessments, Publics and Digital Traces of Controversy: An Experiment in Mapping Issues with Carbon Dioxide Removal Researchers

Laurie Waller

*University of East Anglia, School of Environmental Sciences, United Kingdom & University of Manchester, Department of Geography, United Kingdom/*laurie.waller@manchester.ac.uk

Jason Chilvers

Science, Society & Sustainability Research Group (3S), University of East Anglia, School of Environmental Sciences, United Kingdom

Abstract

Recent scientific assessments of climate change have shifted towards evaluating solutions for removing atmospheric carbon dioxide (CDR). This paper reports a participation experiment in which we involved an interdisciplinary group of researchers in mapping issues relating to two CDR approaches: afforestation and bioenergy with carbon capture and storage (BECCS). We describe the responses of individual researchers when presented with visualisations aggregated from posts about afforestation and BECCS on the platform Twitter. We then compare the researchers' responses with a qualitative analysis of a subset of the Twitter data. The analysis highlights challenges the researchers experienced in identifying issues and relating these visualisations to their own research on afforestation and BECCS. We discuss the prospects for bringing experimental approaches to mapping issues, publics and participation into closer relation with science and technology assessments. The paper concludes with reflections on the value of qualitative traditions of STS research for digital controversy analysis.

Keywords: participation, publics, climate change assessments, greenhouse gas removal, digital methods, controversy analysis.

Introduction

Questions about the roles that publics play in assessments of climate change have acquired a new urgency as governments around the world assess the feasibility of large-scale removals of atmospheric carbon dioxide (CDR), a topic that has generated controversy among scientific communities and been dismissed by climate activists as a speculative tech-fix (Beck and Mahony, 2018; Geden, 2016; Markusson et al., 2018). Controversy over CDR proposals has been accompanied by calls for more 'responsible' approaches to assessing climate futures and related programmes of technological innovation. Proponents of responsible assessment argue that climate assessments

need to become more reflexive and anticipatory about the social, technical and environmental futures CDR may bring forward (or foreclose) while being responsive to public concerns about developments in the science and politics of climate change (Beck and Mahony, 2018; Stilgoe et al., 2013). Approaches to 'participatory assessment' have long been experimented with in STS and cognate fields as means of involving publics in organised science and policy assessments, most often through 'invited' deliberative means (e.g. Darier et al., 1999; Guston, 2014). However, such invited participatory fora and formats have been criticised for eliciting public views in ways that exclude, and obscure, the different issues and forms of engagement that emerge around sociotechnical and environmental controversies, potentially fuelling antagonisms around processes of organised assessment (e.g. Callon et al., 2009; Chilvers and Kearnes, 2016; Wynne, 2007).

Recent work on participation in STS has thus sought take a different approach to the problem of public involvement, moving beyond invited forums to map diverse public engagements in wider issues, controversies and ecologies (Marres, 2015; Chilvers et al., 2018). These methods for mapping issues, publics and participation are yet to applied to the aforementioned challenges of responsible and participatory assessment. In this paper we therefore explore how such mapping methods – and digital controversy analysis in particular – might contribute to the practical task of assessing a controversial topic like CDR.

A variety of approaches propose that analysing 'digital traces'[1] of interaction recorded by online platforms can contribute to engaging publics with processes of issue formation between research, policy and innovation (Marres, 2015; Venturini, 2010). Experiments with repurposing digital records for social research have widely used climate change as a test case for methodological development (see examples in Rogers, 2013). However, these studies have so far taken place at a distance from scientific assessments of climate change, in relation to which digital platforms are predominantly engaged as media for communicating scientific consensus around assessments, such as those of the Intergovernmental Panel on Climate Change (IPCC), rather than as sites of issue formation (Pearce et al., 2019).

This paper presents the results of a participation experiment in which we involved an interdisciplinary group of researchers in the process of mapping issues relating to two CDR approaches: afforestation and bioenergy with carbon capture and storage (BECCS). Situated in the context of a project assessing afforestation and BECCS, we designed an experiment to involve the assessment researchers in the analysis of posts about afforestation and BECCS on the platform Twitter.

The first section of the paper presents an overview of controversies emerging around assessments of CDR and the different roles participation experiments can play in engaging science and technology assessments with publics. In the second section, we outline the issue mapping methodology and the experiment involving the assessment researchers. The subsequent analysis first describes the responses of the researchers to different aggregated visualisations assembled from the digital records collected from Twitter. We then compare the researchers' responses with a qualitative analysis of a subset of the Twitter data. The discussion situates this analysis in relation to the challenges of bringing public issues to bear on the assessment of controversial topics like CDR which challenge institutional settlements between (climate) science and politics, and raise questions about predominant methods for locating publics and engaging assessment processes with public issues. In concluding, we argue that digital traces of controversy are likely to become more relevant to climate change assessments as they shift towards evaluating CDR methods as solutions for governing the climate. We reflect on the challenges and prospects for bringing experimental approaches to mapping issues, publics and participation into closer relation with assessments of climate change and related techno-scientific developments. We suggest that evaluating the public relevance of digital records collected from platforms like Twitter may require mixed-methods approaches to controversy analysis that draw on longstanding qualitative traditions in STS.

The problem of public involvement in climate change assessments and controversies

Questions of public engagement with assessment processes take on particular significance in the context of CDR proposals which, on one hand, project rapid and sweeping technological and environmental changes while, on the other, often emerge from technocratic bodies, like the IPCC, that organise interactions between scientific and policy elites (Beck and Mahony, 2018; Geden, 2016; Markusson et al., 2018). Traditionally, climate change assessments of the kind undertaken by the IPCC have been presented as building on consensus theories of integrated assessment in environmental science, focusing on producing knowledge about the global climate and reducing uncertainties relating to impacts of future climate change (Hulme, 2009; Jasanoff et al., 1998; van der Sluijs et al., 1998). Controversially, the IPCC's Fifth Assessment report (IPCC, 2014) enacted a shift in assessment style towards addressing 'solutions' to mitigating climate change impacts (Beck and Mahony, 2018), focusing on CDR. The scenarios addressed in the Fifth Assessment report, which informed the 2015 Paris Agreement, rely heavily on 'negative emissions technologies' – chiefly, BECCS and afforestation – to perform future CDR (Geden, 2016). Analysts of controversies over the IPCC's Fifth Assessment have argued there is a need to develop more 'responsible' (Beck and Mahony, 2018) or 'reflexive' (Low and Schäfer, 2020) approaches to climate assessment that take into account the ways that framings of CDR delegate scientific and political agency. Controversies over CDR therefore raise questions about the ways climate assessments perform as processes for issue formation and agenda-setting rather than only the linear procedures for establishing consensus and informing centralised policy-making, described by much literature on climate governance (Markusson et al., 2018).

The feasibility of CDR has been widely assessed in terms of biophysical or techno-economic determinants, with far fewer assessments focusing on social and political dimensions (Forster et al., 2020). A variety of social science studies have raised questions about the roles public participation might play in assessments addressing the feasibility of CDR and its role in social and political responses to climate change (Waller et al., 2020). Recent elicitation processes involving stakeholders from government, industry and civil society have revealed the importance of governance, social acceptability and equity issues which are poorly accounted for in integrated assessment models (Forster et al., 2020; Vaughan and Gough, 2016). Social-psychological research combining surveys and focus groups in the US and UK found that perceptions of the 'naturalness' of afforestation may impact the social acceptance of engineered CDR approaches like BECCS (Cox et al., 2020). Elsewhere an experimental deliberative process on CDR has suggested that discourses of geoengineering may dominate framings of CDR and the ways publics engage with the issue in climate policy (Bellamy and Lezaun, 2017). Although undertaken from a variety of disciplinary orientations, these participation experiments suggest, in different ways, that public debates about CDR do not neatly map onto instrumental framings of BECCS and afforestation in climate policy as 'negative emissions technologies'. They highlight that framing the feasibility of afforestation and BECCS in narrowly biophysical and techno-economic terms, e.g. in terms of resource availability and future innovation, may obscure the performative role that CDR projections and targets play in climate politics and could contribute to public disengagement from climate policy (Waller et al., 2021).

Participatory approaches to integrated assessments of climate change have long centred on the development of procedures for representing public perceptions in scientific assessments and including public views in decision-making processes (e.g. Darier et al., 1999). The inclusion of stakeholders, such as model users and decision makers, in the development of modelling scenarios is common in integrated assessment practice (Tansey et al., 2002). Justifications for public participation in integrated assessment have often centred on challenges of demonstrating accountability of policy evidence produced by complex computational models (van der Sluijs, 2002). Approaches experimenting with the involvement of so-called 'lay publics' have focused both on the ways in which participation

can expand the range of knowledges considered, for instance in scenario development, and the expansion of environmental problem definitions (Darier et al., 1999). Climate change-focused assessments involving citizens have often held dual aims of both connecting scientific uncertainties with social issues and, more pedagogically, informing citizens and raising awareness of their environmental impacts (Kasemir et al., 2000). Criticism of participatory approaches from integrated assessment practitioners makes clear that such experiments have often been seen to lack instrumental value for decision-making (van Asselt Marjolein and Rijkens-Klomp, 2002). Such criticism arguably highlights the predominance of consensus-oriented approaches within the integrated assessment community as well as an underlying political realism regarding the (linear) relations between policy-relevant, but neutral, scientific assessments and political decision-making about climate policy (Jasanoff et al., 1998).

This predominant version of participatory assessment has most often assumed an 'invited', 'realist' and representational approach to participation and publics (Chilvers and Kearnes, 2016; Wynne, 2007), whereby participating publics are invited by science and policy institutions into organised processes of public deliberation and elicitation that are seen to represent and correspond to the views and concerns of an external pre-existing public. Recent work on participation in STS and the study of public involvement with controversial technoscience issues highlights some shortcomings of such approaches to public participation in environmental and technology assessment. Social studies of scientific controversy have demonstrated the ways in which formal methods for representing public views, for instance surveys of risk perceptions, can obscure uncertainties, exclude distributed public engagements, and contribute to inflaming antagonisms (Callon et al., 2009). Such analysis has long cast scepticism on the capacity of organised participatory assessment to 'open-up' (Stirling, 2008) the instrumental framings of issues by governing authorities and prevailing political-economies that organise science and innovation (Jasanoff, 2003). Rather than democratising control over science and technology, common categories structuring public participation in assessments, such as distinctions between stakeholders and 'general publics', can therefore foreclose certain framings of issues and remove topics from the domain of legitimate public contestation (Irwin and Michael, 2003).

In response to such critiques, more experimental and relational approaches to public participation in STS have often therefore aimed to both detect issues that may be only latent in, or framed out of, organised assessments and create the social basis for novel forms of political collectivity to emerge (see discussions in Callon et al., 2009; Chilvers and Kearnes, 2016; Irwin and Michael, 2003; Lezaun et al., 2016). Such approaches highlight that the issues emerging around controversial topics like CDR are often not reducible to propositional form, and thus are not easily accommodated within traditional formats of scientific and policy assessment. Rather, such issues are often inseparable from the collectives and media that give them public expression and are thus often conceptualised as 'issue publics' (see discussion in Madsen and Munk, 2019). Bringing experimental approaches to participation into closer relation with organised assessments therefore raises questions about the ways methods for mapping issues relate to procedures for representing publics in organised assessments as well as to the processes through which controversial topics like CDR become publicised as such.

In exploring how emerging methods for mapping issues, publics and participation might contribute to assessments of CDR, our focus in this paper is on digital methods and digital controversy analysis in particular. This is far from the first time digital media-technologies have been considered as a means of public engagement with integrated assessment processes. However, previous proposals have assumed an invited model of participation where questions of public relevance are defined by scientific and policy elites. We see this, for instance, in the way Tansey et al. (2002) described the development of a regional integrated assessment model and the participatory possibilities offered via internet access:

Since the model has been developed to be used via the internet, stakeholder access on an

unprecedented scale will be feasible and it will be possible for individuals and groups to use the model iteratively and to experiment with a range of scenarios. (Tansey et al., 2002: 102)

Through opening up to multiple forms of public relevance, our approach instead invites questions about the extent to which digital methods research might experimentally mediate between organised assessments and diverse publics that emerge around the controversial topics and objects assembled together in assessment processes.

The roles played by digital media-technologies, such as online platforms, in giving expression to public issues has provided a significant focus for recent methodological and conceptual developments in public engagement with controversial technoscience topics (Marres, 2015; Venturini, 2010). Debates about the repurposing of digital media-technologies as 'digital methods' for social research highlight that analysis of public issues today often has to confront problems of 'web epistemology' and questions of how digitally-mediated information gains visibility and is accepted as reliable (Rogers, 2013). Digital methods research has therefore provided a site for methodological experiments in analysing not simply representations of controversial technoscience topics in digital media coverage but examining the media-technological artifice involved in staging a topic or object as controversial (Marres and Moats, 2015; Venturini, 2010). Underlying digital methods experiments therefore is the notion that the social interactions and public expressions recorded by digital media-technologies are highly artificial and enact particular epistemological assumptions about how to measure and assess the public relevance of a topic and what makes an issue (Marres, 2015; Rogers, 2013).

Research that repurposes digital platforms as instruments with which to map public issues therefore raises questions about the potential for media bias and, relatedly, the partiality of digitally-mediated knowledge claims. Rather than treating digital platforms as reservoirs of data about public opinions, Marres (2015) argues that where the notion of the 'trace' maintains reference to the artifice involved in the recording of interactions and articulations by digital media-technologies. Rather than attempting to limit the bias of a medium, issue mapping research empiricises the problem of media effects in order to attend to the role digital platforms play in the enactment of controversy and public concern (Marres, 2015). Such an approach draws on observations relating to the performativity of digital controversy; that is, the study of controversies on digital platforms necessarily implies judgements by the researcher about the public relevance of the platform itself (Marres and Moats, 2015). A central methodological focus of issue mapping research therefore relates to how to test the findings of platform-based research and their public relevance (Madsen and Munk, 2019). The issue mapping experiment presented below can, we propose, be understood as exploring the roles digital methods can play in bringing public expressions on digital platforms to bear on the practices of researchers engaged in scientific assessments as well as contributing to debates about how to evaluate the public relevance of platforms like Twitter.

Methodology

The issue mapping approach developed in this study comprised a mixed-methods research design involving digital methods and semi-structured interviews. Between November 2018 and June 2020 the authors tracked Twitter terms relating to (1) bioenergy with carbon capture and storage (BECCS) (n=7,936), and (2) afforestation and reforestation (n=30,116).[2] The study engaged a group of interdisciplinary CDR researchers – with whom the authors were collaborating on a project assessing the feasibility of CDR from afforestation and BECCS[3] – in the issue mapping process through individual interviews. Participants were interviewed about the feasibility of afforestation and BECCS and then asked for their responses to visualisations assembled by aggregating (in different ways) the digital records collected from Twitter. We subsequently hand-coded a subset of the Twitter data to compare the researchers responses to the aggregated visualisations with the findings of a qualitative analysis.

The platform Twitter was chosen as a field site both because it is widely used by individual scientists and has been widely studied as a setting

of climate change debate (Pearce et al., 2019). The semi-structured interviews undertaken involved 12 researchers with whom the authors were collaborating on a project assessing the feasibility of large-scale removal of greenhouse gases via BECCS and afforestation. Participants included researchers from a variety of disciplinary backgrounds, including earth systems science, geography, biology, chemical engineering, economics, physics, political science and psychology. Prior to the interview, participants were asked to spend 10 minutes reading through a 'dossier' constructed from tweets collected about BECCS and afforestation. They were then asked to spend a further 10 minutes exploring two network visualisations showing the co-occurrence of hashtags in each dataset (see figures 2a & 2b), following a navigation guide provided.[4]

The dossier provided to participants visualised the following aggregated material relating to tweets about afforestation and BECCS:

- Overview of tweets collected (total number of tweets, number of retweets, number of replies, number of links, number of hashtags)
- Timeline visualisation of posting activity, by day (November 2018 to June 2020)
- Ranked list of 20 most frequently posting users
- Ranked list of 20 most frequent URL domains appearing in tweets (e.g. twitter.com)
- Ranked list of 20 most frequently retweeted posts

The network visualisations of co-occurring hashtags were constructed from original tweets (i.e. after removing duplicates), using the Table2Net software.[5] In the BECCS dataset 31% (n=2,448) of tweets contained two or more hashtags compared with 21% of tweets (n=6408) in the afforestation dataset. Each file was visualised in Gephi, removing the search terms and spatialising using the forceatlas2 layout algorithm (Jacomy et al., 2014). Node labels were sized according to term frequency in the dataset and the edges (links) between nodes were weighted by the number of connections, represented by thickness. The networks were then uploaded to an interactive network explorer software called mini-VAN software.[6] The links to the 'co-hashtag' visualisations (Marres, 2015) were given to participants along with the dossier.[7]

Co-hashtag analysis draws on co-word analysis techniques from actor-network theory that, in their early formulation, analysed the co-occurrence of keywords in scientific papers to identify emerging research problems between established research fields (Callon et al., 1986). Twitter hashtags are designed to enable users to attach content to topics that may cut across sub-communities on the platform. In principle, hashtags, like keywords, facilitate interactions around common topics rather than only between immediate networks of friends and followers. However, unlike scientific keywords, hashtags are not simply used as associative devices. We therefore treated the co-hashtag networks as experimental visualisations that may reveal as much about platform dynamics as about issue dynamics in the field of CDR (Marres, 2015). This enabled us to pose the relevance of the issues emerging on Twitter as a question that may have different answers depending on a particular researcher's relation to the platform.

The interviews aimed to both elicit substantive responses of participants as CDR experts and their personal and professional responses to Twitter as a prospective site of public engagement with CDR issues. In the interviews, participants were first asked about the feasibility issues that their research on BECCS and afforestation identified and their relationship to Twitter. They were subsequently asked for their responses to the dossier and the network visualisations and the extent to which feasibility issues could be detected in these. Verbal explanations of the network visualisations were provided drawing the analogy, outlined here, between co-word analysis in science studies and the study of emergent problems. Finally, participants were asked to reflect on the interview process, whether engaging with the visualisations had altered their prior view of Twitter as a setting of engagement and if any consequences followed for their research.

As we discuss below, the analysis of the interviews identified a series of platform-based contrasts between the afforestation and BECCS publics, which we characterise as 'Twitter-spheres'. In a subsequent step we therefore designed a test to compare the responses of the researchers with the results of a qualitative analysis on a subset of the Twitter data. To construct the subset of Twitter data we queried the afforestation and BECCS

datasets for land-related issues. Land use issues were chosen because both BECCS and afforestation are likely to require significant land use change for biomass plantation and the avoidance of land use conflicts is a central feasibility issue for both of these CDR approaches (Waller et al., 2020). Using the TCAT software we queried the afforestation and BECCS datasets for the terms [land][8], [landuse]. This returned 142 BECCS tweets (5% of unique tweets in the dataset) and 352 afforestation tweets (6% of unique tweets in the dataset). The hashtags occurring in these tweets were coded onto the co-hashtag networks (constructed in the prior stage) for comparison.

The tweets in the land-related samples were then qualitatively analysed using a typology distinguishing between six dynamics of public engagement with the assessment of technoscientific issues. These six dynamics refer to rhetorical repertoires deployed by individuals and collectives to publicise and frame the issues being assessed, raise concerns and interact with other implicated actors (in the analysis below we use the shorthand of "repertoires of public assessment"). The typology was constructed on the basis of studies of CDR discourse (Waller et al., 2020), and draws on distinctions between modes of social appraisal and public engagement with environmental and technology assessment as well as existing typologies of science-policy interaction (Irwin and Michael, 2003; Pielke, 2007; Stirling, 2008). The typology is therefore premised on a symmetrical approach to the assessment of technoscientific issues, as a practice that heterogeneous actors engage in, not only those authorised to do so by scientific and policy-making institutions. The six categories we distinguish between are as follows:

1. *Claims scientific authority*: tweet makes scientific claim or invokes (social) scientific authority (e.g. link to journal paper).
2. *Contests a fact*: tweet contests a factual claim and offers counter-evidence (e.g. raises questions about a modelling scenario). Not necessarily a scientific authority.
3. *Mediates debate*: tweet considers competing evidence or links to issue-neutral source (e.g. news, policy paper).
4. *Partisan stance*: tweet takes an activist or partisan stance on a particular issue or suite of issues.
5. *Promotes solutions*: tweet promotes practical solution (e.g. commercial publicity, government programme, grassroots initiative).
6. *Transgressive*: tweet denounces authority or questions legitimacy of particular CDR-related assessments or proposals (e.g. radical activist, conspiracy theorist, independent researcher).
7. *Other* – idiosyncratic publicity on afforestation or BECCS e.g. job adverts.

The two authors applied these categories independently to the samples of land-related tweets and then compared results. Where contradicting categories were identified the cases were discussed and either corrected, if it was agreed that an error had been made, or highlighted as a case that challenged the typology (categories were agreed for 95% of BECCS tweets and 97% afforestation tweets). Our approach to the use of categorisation is therefore as a controversy heuristic as well as an approach to ordering information. As our analysis highlights, there appeared some obvious cases of tweets that were not easily reducible to a single category. We also note that within a given category tweets could articulate more-or-less pluralistic stances towards the actors, evidence or solutions relevant to CDR e.g. tweets coded '*Promotes solutions*' could promote multiple policy measures, technologies and lifestyle changes or, conversely, a single innovation.

Mapping afforestation and BECCS-related issues with CDR researchers

The interviews involving the researchers were in various ways porous spaces of interaction. The participants in our study related to us intellectually as social scientists but also in organisational terms as colleagues involved in an interdisciplinary scientific assessment project. Early on in the project, for instance, we had circulated the list of query terms that were being tracked on Twitter to project members and invited feedback on the query design. Most participants had also attended quarterly project meetings where we presented preliminary insights and given feedback. And, we

had at various points engaged in discussion about the aims and outputs of the collective assessment. By the time of the interviews, most participants were therefore both familiar with the aims of our research and, to varying degrees, had engaged in some form of intellectual exchange with us. Their responses to interview questions are therefore not only those of researchers defined only by their discipline or expertise but those of colleagues involved in a common interdisciplinary assessment process who, by design, hold a variety of (sometimes competing) perspectives on the feasibility of afforestation and BECCS and how it should be defined and assessed.

The researchers' views about the value of Twitter for public engagement did not neatly map onto user/non-user distinctions. Of the twelve researchers interviewed, seven had Twitter accounts which were predominantly used in a professional capacity. While several users and non-users suggested the platform had potential to facilitate public engagement with topics like CDR, scepticism about the value of Twitter for public debate was prominent among both users and non-users. Notably, none of the researchers with accounts regularly engaged in interactions on the platform beyond publicising their own work. In line with studies of climate change on Twitter (Pearce et al., 2019), most researchers approached the platform primarily as a medium of science communication rather than an interactive setting of debate and issue formation. However, the challenge of mapping researchers' views about Twitter onto their status as users/non-users suggested that participation on the platform was rarely simply a personal choice. Indeed, both users and non-users highlighted a range of institutional and professional rationales, or conventions, relating to the widespread use of the platform among academic researchers.

In response to questions about the location of public debates on afforestation and BECCS (i.e. an open question that was not specific to Twitter), the researchers articulated a variety of ways in which publics can engage with CDR assessments. Researchers' answers sometimes offered competing constructions of the public to which their assessments are addressed. For instance, the account below, given by R2, demarcates public issues from the "critical issues" addressed by experts and stakeholders:

> The mechanisms which will drive change to afforestation and BECCS are going to be between government, the energy industry and landowners. So that for me is where I see some really critical issues coming to light. Which is a bit different from some of the public issues that I think yourself and Jason were interested in. (R2)

Such an account arguably forecloses more pluralistic accounts of issue formation in assessment processes, such as articulated by R5 below:

> You could say the ways publics are engaging with CDR is very different. Industrial CDR tends to get a lot of traction in the press, partly because the developers are often looking for heavy capital investment and start-up investment. By contrast, issues relating to nature-based solutions play out at quite specific place locations and contexts, so they don't flare up in the same way. (R5)"

While we refrain from attributing positions to individual participants, in general those participants whose answers could be identified more closely with the first position tended to be more expressly critical of the unrepresentative nature of Twitter. In contrast, those participants adopting more pluralistic positions on issue-formation tended to view the partiality of Twitter in experimental terms rather than as a limitation for public engagement with scientific assessments. In line with the prominent scepticism about Twitter amongst the researchers, the first position appeared much more prominent in the interviews than the latter.

By engaging participants with the dossier and the co-hashtag networks we aimed to test contrasting visualisations of issue dynamics on Twitter: the dossier visualising a series of ranked lists based on aggregated measures (e.g. retweet frequency), the co-hashtag networks as visualising relations between heterogeneous issue-terms. However, such contrasts appeared less significant (insignificant in some cases) in the responses of interview participants than those drawn between afforestation and BECCS publics.[9] Partly an effect of our interview design, the participants spent far more time engaging with the dossier than with

the co-hashtag visualisations. As we highlight below, many (though not all) struggled to engage with the visual complexity of the co-hashtag networks. Because the ranked lists in the dossier offered a formal and immediate means of comparison, this material appeared the primary basis on which participants drew contrasts between afforestation and BECCS publics. These contrasts were often made in the guise of informal remarks or personal reflections. For instance, many participants described their feelings about the lists of user accounts or used evaluative language, like "positive", to characterise the sentiments expressed by retweeted posts or hashtags. This kind of interview speech does not therefore represent strict analytical statements of interpretation. Instead, we treat the contrasts between afforestation and BECCS publics articulated in the researchers' engagements with the visualisations as propositions about distinctive platform-based public spheres, or 'Twitter-spheres' as we term them (see Table 1), that can be empirically tested.

In what follows we first briefly outline the thesis of distinctive afforestation and BECCS Twitter-spheres. We then analyse how these contrasting Twitter-spheres might partially account for the struggles experienced by participants' in identifying issues and detecting controversy in the visualisations. Finally, we test the Twitter-spheres against a sub-sample of tweets addressing land-related issues, which were qualitatively analysed and compared using a typology distinguishing repertoires of public assessment (outlined in the methodology).

Constructing afforestation and BECCS publics as Twitter-spheres

The construction of these two Twitter-spheres, represented in Table 1, is necessarily crude as a representation of participants' responses to the visualisations. The contrasting Twitter-spheres are premised on oppositions, such as between the ratio of posts that are replies (i.e. an indicator of discussion), organisational vs. individual users, links to scientific sources vs. links to news sites, or posts that represent critical arguments vs. those that distribute acclaim.

In practice, the contrasts drawn by participants were rarely premised on such clear-cut oppositions and were often heavily caveated or reflexively advanced, for example:

> Contrary to the BECCS dataset, I think the afforestation dataset had much more of a green grassroots kind of vibe. I know that's probably not a very good way of putting it, but there are much more words like natural solutions and this kind of thing surrounding afforestation, with not too much emphasis on policy. (R7)

While the drawing of such contrasts comprised a central dynamic of the majority of interviews, participants also made observations about features of the visualisations that complicate strong oppositions and highlighted commonalities e.g. users common to both or retweets that address afforestation and BECCS together. In the case of the dossier material relating to BECCS several participants also highlighted internal contrasts between lists, for example:

Table 1. Contrasting afforestation and BECCS Twitter-spheres.

	BECCS Twitter-sphere	**Afforestation Twitter-sphere**
Overview dataset characteristics	Few posts, high number of posts replying to another	Many posts, low number of posts replying to another
Frequently posting users	Policy actors, Europe-centric	Companies and individual activists, globally distributed
Frequently linked-to domains	Science sources, climate policy organisations, industry sites	News sites, environmental organisations, business sites
Style of frequently retweeted posts	Critical, policy-focused	Distributing acclaim, climate change-focused
Co-hashtag networks	Climate policy-related hashtags, international organisations, acronyms e.g. conferences	Climate change-related hashtags, campaign slogans, country names, sustainability terms

> [The list of most frequent BECCS user accounts] looks an interesting potpourri, doesn't it? It looks like a mixture of the academic, the concerned or interested individual campaigner… a bit of the business space. […] I don't know what to make of that really because I think the messages, the most re-tweeted messages themselves [don't reflect this]… you would expect this set of most frequent posters to represent a more diverse set of views, and presumably they do, they've just not been re-tweeted! So, the magic of Twitter is picking up one pole of what must be a more, a more mixed set of… positions. So, I'm encouraged in short by the poster list… but, it doesn't reflect in the resulting dominant discourse. (R6)

Such distinctions at once illustrate the nuanced ways in which participants engaged with the material but also highlight how latent imaginaries of the platform, and the processes by which material posted gains public relevance, were often implicit in responses. Notions like "dominant discourse" here imply that it is by aggregation of retweets that a post becomes discursively powerful on the platform. Such imaginaries are significant given that aggregative metrics of engagement are widely deployed by platforms to establish public relevance (Marres, 2015), such as Twitter's Trending algorithm, and which our issue mapping approach was precisely designed to push back against.

The afforestation and BECCS co-hashtag visualisations provided to the participants each comprised a single, visually complex, network (see Figures 2a and 2b). Table 2 (below) shows the most highly connected hashtags in the networks provided to participants (coded versions of the network visualisations can be found in figures 2a and 2b in section 3).

Responses to the networks varied but often appeared shaped by the prior discussion of the material in the dossier. Some participants suggested the networks were too complex to meaningfully engage with and it is notable that two participants abstained from venturing interpretations of the visualisations, instead suggesting that further quantitative reduction of complexity would be required for such a task (e.g. applying a clustering algorithm). The latter responses highlighted tensions in the network style of visual presentation which could be interpreted as homogenising relations between hashtags (e.g. a semantic network of relations between words) as much as mapping relations between heterogeneous issue-terms and material-semiotic entities (see Marres, 2015). Indeed, the above tables showing most highly connected hashtags might suggest some dimensions of heterogeneity. The BECCS network, for instance, includes broad thematic hashtags, such as #climatechange, an organisation, the #ipcc, conference names, #cop24 and #cop25, a reference to corporate social responsibility, #esg, and a campaign slogan, #axedrax. A number of participants noted the challenge of interpreting the meanings of hashtags in both networks, high-

Table 2. Ranked list of most connected hashtags appearing in the afforestation and BECCS co-hashtag networks.

BECCS co-hashtag network[10]			**Afforestation co-hashtag network**		
Hashtag	**Number of tweets containing hashtag**	**Number of links to other hashtags**	**Hashtag**	**Number of tweets containing hashtag**	**Number of links to other hashtags**
climatechange	122	134	climatechange	683	781
climateaction	43	105	climate	182	349
ipcc	49	86	carbon	104	256
cop24	22	77	climateaction	134	240
trees	11	75	environment	88	205
climate	56	56	co2	85	202
netzero	103	52	sustainability	55	151
esg	8	50	globalwarming	54	141
cop25	17	48	nature	37	140
axedrax	4	47	biodiversity	41	127

lighting the presence of acronyms and specialist terms, notably in the BECCS network. Platform-specific dynamics are also arguably evident in the table, with several of the highly connected BECCS hashtags appearing in relatively few tweets (#axedrax appears in only 4 tweets), their visibility here an artefact of a user technique of maximising the number of hashtag within Twitter's character limits, potentially a strategy attempting to maximise the visibility of the post via the platform's popularity-based algorithms (Rogers, 2013) rather than for connecting content to a specific cross-cutting topic.

A variety of participants contrasted the network visualisations in a similar manner to the material presented in the dossier, for example:

> What really emerges for me quite strongly by looking at the BECCS hashtags map is the prominence around climate change, around kind of embeddedness or discussions of BECCS within scientific circles like the IPCC and related conferences … [it's] more technological orientated conversations within national strategies around decarbonisation... Whereas, if I look at the afforestation one what I see is still a kind of prevalent framing around climate change and potentially climate change mitigation but, it's considering more the characteristics of forests, what they provide, things about carbon absorption, the additional cultural benefits or ecosystem service benefits that they provide and their embeddedness within more complex and wider conversations around sustainability as well.(R14)

Such accounts not only articulated thematic contrasts but also some distinctive ways in which hashtags can perform as publicity devices, for instance to connect to a "conversation" or promote a slogan.

Notions of the public were invoked (sometimes latently) by researchers to explain contrasts between afforestation and BECCS visualisations. For example:

> There were some [afforestation retweets that say] "keep calm and plant a tree", and another one and another one … you know, no-one's going to argue with that, it's easy to put out there whereas if you go, "keep calm and make a BECCS plant", people are going to kick off. (R11)

The use of notions of the public to explain contrasts between afforestation and BECCS visualisations was neither shared by all researchers nor ventured in a schematic way. While often appearing partial or informal, they nonetheless highlight how strongly evident the contrasts between afforestation and BECCS publics appeared to some participants, to the extent that their differences warranted explanation. Such explanations highlight how the afforestation and BECCS Twitter-spheres we identify here could be said to correspond to distinctions between natural and engineered CDR i.e. distinctions not only between methods but also, more normatively, to differences between perceived 'naturalness' and social acceptability of CDR (see Cox et al., 2020).

How Twitter-spheres obscure traces of controversy

One of the most striking results from the interviews was that participants overwhelmingly answered "no" to the question: "does this material on BECCS and afforestation raise any feasibility issues that you were previously unaware of?".[11] The interview design was intended to begin by discussing the feasibility issues arising from each participant's research on afforestation and BECCS as a basis for subsequent exploration of the visualisations. However, such assumptions of continuity between research problems and public issues appeared highly questionable. While the dossier and network visualisations were often characterised as "interesting" and "surprising", when the question was explicitly posed the researchers appeared to reject the notion that the visualisations raised substantive issues that might have consequences for their research assessing the feasibility of afforestation and BECCS.

While many participants struggled to identify issues relevant to their research, they also offered divergent evaluations of the visualisations. Studies of scientific discourse (Gilbert et al., 1984) have long shown that the appearance of epistemological consensus can be supported by multiple empirical justifications. In examining participants' responses to a range of interview questions we found sometimes competing, though equally plausible, ways in which separations were drawn

between scientific concerns about the feasibility of afforestation and BECCS and public issues.

The most frequently retweeted post in the BECCS dataset provides an illustration of divergent responses between researchers, who otherwise agree that the visualisations failed to problematise establish issue-framings. The tweet both publicised and linked (indirectly via a media report) to a journal article, involving researchers participating in our interviews, titled: *Land-use emissions play a critical role in land-based mitigation for Paris climate targets*. The tweet reads:

> Trying to tackle climate change by replacing forests with crops for bioenergy power stations that capture carbon dioxide (CO2) could instead increase the amount of CO2 in the atmosphere, scientists say. #ActOnClimate #ClimateChange https://t.co/pDqDFkSzOI. (Dawson, 2018)

This tweet was not authored by the researchers on our project but rather by a user describing themselves as a "climate change communicator" and who, notably, also authored the most frequently retweeted post about afforestation in the dossier (a fact that might suggest the well-documented 'Matthew effect' in science can also apply to platforms like Twitter, see discussion in Marres, 2015).

As the most frequently retweeted post in the BECCS dataset, this tweet was highlighted or discussed (to varying degrees) in the majority of interviews. However, while the authors of the journal article it links to both recognised, unprompted, that the tweet was referencing their research, no other participants recognised this fact. Four participants offered an evaluation of the tweet as either "critical" or "negative". In some interviews we drew participants' attention to the connection between the tweet and their colleagues' research and asked whether learning this changed their evaluation of the tweet. Although none of the researchers revised their initial evaluation of the tweet, this question did elicit a variety of justifications that can be compared. One researcher, for instance, suggested the tweet represented a partisan interpretation that took some of the claims of the paper out of context:

> **R12**: The trouble is that I think they make a lot of uninformed comments about bio-energy being intrinsically more dirty than coal and I think they come from that perspective. Whilst it's true that a bio-energy power station will emit more carbon per megawatt hour, they don't take into account the growing of the material… so they don't consider the whole lifecycle.
>
> **Interviewer**: Does it make a difference that the link in that tweet is to a story that reports a paper published by [researchers], from our project?
>
> **R.12**: No [laughs]. Because it's probably taking something out of context. [...] I think if you go to [the] paper, for example, they discuss it at length, the circumstances over which it might not be very good and the circumstances at which it may be good but overall, the paper is for BECCS rather than against BECCS, so to speak.

The researcher's original objection to claim in the tweet is here justified on the basis that the nuance of the original research is lost in its translation in media reporting, and in the subsequent tweet, enabling the paper to be appropriated to support partisan arguments against BECCS. The researcher's suggestion that the paper is "for" BECCS here highlights the challenge of positioning assessment research in relation to systemic criticism of CDR in climate policy (i.e. that approaches promoted as CDR may be in fact lead to net increases in CO2 emissions). Rather than reading the researcher's comment as a statement of partisanship we suggest dichotomies between constructive and critical approaches to CDR are better understood as artefacts of policy-driven approaches to scientific assessment.

Other justifications for similar appraisals of the tweet, however, differed in where they located the causes of the partial interpretation of the research. One focused on limited public access to academic journals. Another related the partial reporting of the paper to the focus on "headline grabbing" in contemporary academic research. In such responses, the causes of partial reporting of CDR research lay not only in the particular motivations of Twitter users or the discursive limitations of the medium but also in the publishing and publicity practices of researchers and scientific institutions. By contrast, a researcher who did not evaluate

the tweet as critical or negative highlighted that it could be read as raising scientific and policy questions about the challenge of assessing CDR approaches like BECCS and afforestation independently, when they might potentially compete for land.

Indeed, several interview participants explicitly foregrounded the absence of land and land use issues. For instance:

> [The visualisations] didn't seem to tell you anything about the land debate whatsoever … in terms of policy design, agri-environment, farmer succession, longevity in the way in which we try and do this … all those real issues we're trying to get afforestation going, it doesn't really come out in here. (R2)

As illustrated in the discussion of the most retweeted BECCS post above, land-related research issues were potentially detectable in the visualisations, however, participants struggled to identify them as such. As a concern for scientific assessments of both afforestation and BECCS, land-related issues therefore provided a case with which to test the Twitter-spheres constructed from the interview responses.

A test of the afforestation and BECCS Twitter-spheres

In order to test the construction of afforestation and BECCS Twitter-spheres emerging in the responses of the researchers we analysed samples of tweets about land use (see methodology). The queries for [land] and [landuse] returned similar sample sizes (as a proportion of each dataset, see methodology) suggesting that land-related issues may not support strong contrasts between afforestation and BECCS publics (as the Twitter-spheres in Table 1 might otherwise imply). Our test compared issue dynamics in these samples both by categorising the tweets they contain and by coding the hashtags in these tweets onto the network visualisations.

Categorising the land-related tweets against the typology (outlined in the methodology) affirms some aggregate contrasts between public expressions about afforestation and BECCS on Twitter (see Fig.1). The most prominent dynamics in each sample could be said to correspond to contrasts identified in the Twitter-spheres table (above): almost 40% of land-related tweets in the BECCS appear to mediate between positions in policy debates while almost 35% of land-related tweets in the afforestation sample promote solutions. In relation to the Twitter-spheres, this contrast could be seen to affirm some aggregate differences between afforestation and BECCS publics and social realities of CDR.

However, attending to the antagonistic modes of engagement[12] – represented by the categories: '*Contests a fact*', '*Adopts partisan stance*' and

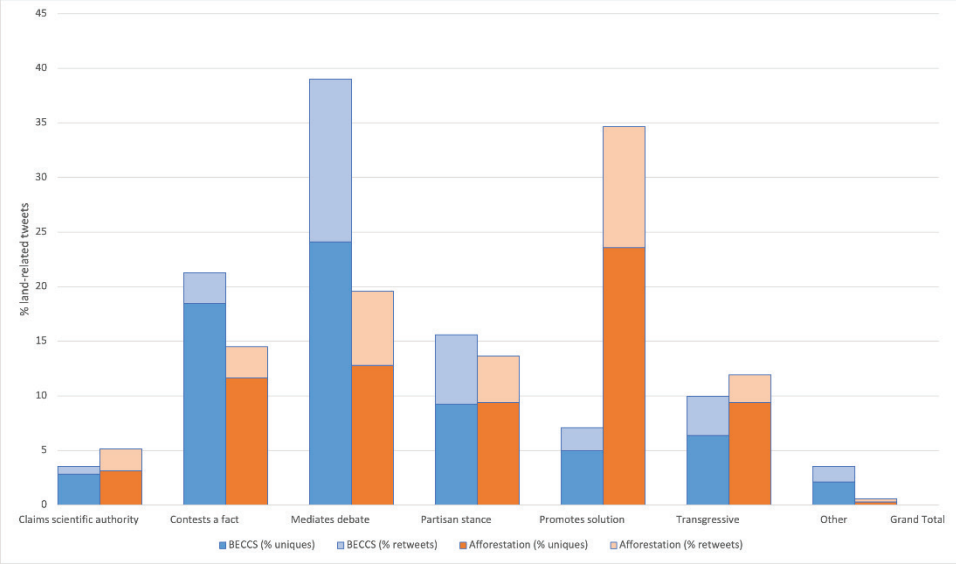

Figure 1. Comparison of land-related tweets in afforestation and BECCS datasets, tweets categorised by typology of repertoires of public assessment (see methodology).

'*Transgressive*' (which together account for 40% of afforestation tweets and 47% BECCS tweets) – complicates suggestions that contrasts between these samples can be explained by inherent properties of afforestation and BECCS as CDR methods (e.g. as simply reflecting different 'technology readiness levels' (c.f. Nemet et al., 2018). This point can be illustrated with the example of a tweet that challenged the authors' categorisation typology:

> Great columm from @Richard_Dixon on #bioenergy with carbon capture & storage: "BECCS as an idea [...] has a terrible reputation, mainly because of the huge areas of land that would be needed [...], but also because, done wrong, BECCS would actually make climate change worse."(Biofuelwatch, 2020)

In this tweet the activist group Bioenergy Watch refers to a report in the newspaper *The Scotsman* authored by the director of Friends of the Earth Scotland about potential developments of BECCS in Scotland. Based on the user, one author categorised the tweet as *Partisan Stance* while the other categorised it as *Mediates Debate*, based on its link to a newspaper source. While the contradictions this tweet raised for our typology were much less apparent in the majority of the corpus, they nonetheless highlight the ways in which digital interactions recorded by platforms like Twitter can complicate, even confuse, institutional and actor-based categories e.g. in this case between mediators and interest groups. The exercise of categorisation affirms that, in the aggregate, contrasting topic dynamics are prominent in the afforestation and BECCS samples. However, we also see how, in this example, controversy dynamics may be obscured in processes of aggregation.

Tensions between aggregate methods of analysis and the detection of controversy dynamics surface prominently in the coded co-hashtag network visualisations.

In aggregate terms, there are clear differences between the proportion of land-related hashtags in each network: in the afforestation network, 11% of hashtags appear in land-related tweets (though only 5% are unique to land-related tweets), in the BECCS network 6% of hashtags appear in land-related tweets (though only 1% are unique to land-related tweets). However, a close visual analysis arguably suggests not dissimilar patterns of hashtag use in both. In both networks land-related hashtags are polarised between those nodes with very high numbers of links in the network and those with very low numbers of links. The nodes with the most links in each network represent hashtags that also occur in many tweets not relating to land e.g. #climatechange. Hashtags occurring only in land-related tweets often appear in weakly connected clusters of hashtags or on the periphery of the network. Common to both networks, then, is a common pattern in which hashtags are used to connect land-related tweets either to popular climate and environmental

Table 3. 10 most highly connected hashtags in land-related tweets in afforestation and BECCS datasets.

BECCS co-hashtag network			**Afforestation co-hashtag network**		
Land-related hashtags	**Number of tweets containing hashtag**	**Number of links to other hashtags**	**Land-related hashtags**	**Number of tweets containing hashtag**	**Number of links to other hashtags**
climatechange	122	134	climatechange	683	791
climateaction	43	105	trees	152	365
ipcc	49	86	climate	182	354
cop24	22	77	carbon	104	260
netzero	103	52	climateaction	134	242
cop25	17	48	environment	88	207
negativeemissions	35	42	co2	85	204
naturebasedsolutions	10	26	deforestation	84	202
ghg	8	18	sustainability	55	154
cdr	5	17	globalwarming	54	143

Figures 2a & 2b. Afforestation (2a) and BECCS (2b) co-hashtag networks, showing co-occurrence of hashtags in tweets. Colour coded for land-related tags: tags unique to land-related tweets (green), tags shared by both land-related tweets and non-land-related tweets (red), tags not appearing in land-related tweets (white). High resolution images available on request.

policy terms (see Table 3) or, conversely, to very idiosyncratic issue-terms e.g. #friendsofhaiti2010, #missingpathways.

Our test offers some reasons for why the researchers may have struggled to detect controversy in the visualisations and identify issues. Qualitatively analysing the tweets highlights how methods of aggregating digital records may obscure controversy dynamics, such as the confusion of actor categories. Methodologically, this illustrates the contingency of platform-focused categories, such as between users and content, and how they can become reified in aggregate contrasts, such as between afforestation and BECCS Twitter-spheres. Coding the co-hashtag visualisations also makes clear why land-related issues would have been difficult to detect in the co-hashtag network visualisations, since land-related tweets tend not to be publicised as such through hashtags. The results of this test therefore raise questions about the extent to which platform-specific categories and devices, like hashtags, can be repurposed as methods for bringing scientific assessments into closer relation with their publics. We now offer some reflections that follow from this finding.

Discussion and conclusions

The kinds of issues that emerge on digital platforms like Twitter have typically been excluded from consideration in scientific assessments of climate change on the basis that they are partial, both in the sense that actors are often self-selecting or unrepresentative of societies and that the knowledge claims they raise cannot be easily validated. Climate change assessments, like those undertaken by the IPCC, are typically concerned with the representation of publics that can legitimate decision-making processes or provide assessment institutions with the basis for demarcating policy stakeholders from lay audiences. However, as climate change assessments shift from addressing the causes of global warming to evaluating solutions like CDR the expansion of knowledges, expertise and concerns relevant to assessments and the drawing of boundaries between climate science and politics – as well as distinctions that often structure public participation in assessments, such as between 'critical' issues and public issues or between stakeholders and 'general publics' – is likely to become more controversial. Attempts to construct CDR as a topic of scientific assessment are therefore unlikely to settle such controversy, and rather more likely to proliferate the sites of engagement with climate change research and settings where the agendas of climate change assessments, and the issues they address, are discussed and contested. This study has sought to examine the extent to which digital media-technologies, like social media platforms, can stage assessment-related controversies and bring climate assessments into closer relation with public issues. By way of discussion and conclusion we now draw out three main areas of insight from the study on: relations between climate/CDR assessments and their publics; prospects for bringing mapping methods into critical proximity with processes of interdisciplinary assessment; and implications for digital methods and controversy analysis.

First, the issue mapping experiment presented in this paper developed within an assessment process organised around large quantitative CDR targets and, more broadly, prevalent framings of public engagement as a problem of legitimating CDR policy options and securing the social acceptance of technological innovations (Waller et al., 2020). Involving the researchers in the issue mapping process did not return a neat slate of issues in ready-made propositional form relating to the afforestation and BECCS and the assessment of CDR feasibility. Instead, we found many participants engaged with the visualisations by drawing contrasts between afforestation and BECCS publics, which we have characterised here in terms of their platform-specify, as Twitter-spheres. The contrasting Twitter-spheres outlined here arguably correspond to well-established, competing problem-framings of CDR, namely: afforestation as a 'natural solution' to climate change and BECCS as 'geoengineering' (Bellamy and Lezaun, 2017; Cox et al., 2020). Quantitative CDR assessments have predominantly developed around techno-economic problem framings: treating both afforestation and BECCS as 'technologies' and removals of atmospheric carbon dioxide as exchangeable between them (see discussion in Nemet et al., 2018). While 'natural

solutions' to climate change are often presented by their advocates as normatively desirable alternatives to 'geoengineering', the methods used to assess their feasibility in practice differ little, both privileging technological and economic framings (broadly conceived e.g. to include ecosystems services) of feasibility issues (Waller et al., 2020). The contrasting Twitter-spheres we identify here may therefore map onto contrasting policy discourses relating to CDR but – as highlighted in the researchers' struggles to identify issues relevant to their research – it is not clear that such differences necessarily problematise predominant techno-economic approaches to assessing the feasibility of afforestation and BECCS or framings of CDR as a solution to governing climate change.

Second, our study offers insights on the challenges and potentials for participation experiments that seek to bring experimental methods for mapping publics, participation and public issues into critical proximity with organised assessment processes. Rather than limit these reflections to prescriptive metrics of successful 'participatory assessment', in taking a more experimental and reflexive approach to participation (Chilvers and Kearnes, 2016; Lezaun et al., 2016) we attempted to attend to the different productivities, openings and closings generated through the issue mapping process. The challenges experienced by the participants in detecting assessment-related controversy and identifying issues has provided the primary occasion for exploring the roles digital methods can play in both engaging and disengaging assessment researchers with public issues. The researchers' overwhelming rejection of the notion that the visualisations raised issues they might previously have been unaware of could be seen as a failure of the experiment to significantly problematise pre-existing framings of the feasibility of afforestation and BECCS. In some public engagement with science approaches, such findings might be interpreted as evidence of 'deficit' models of (Twitter) publics lacking the cognitive resources to engage with the topics of scientific assessments (see discussions in Irwin and Michael, 2003). Conversely, from more critical traditions, it might be tempting to suggest a social science 'deficit' on the part of the participants who did not attribute methodological significance to distinctions between the aggregated lists and co-occurrence network visualisations. However, since almost all interview participants acknowledged some degree of interplay between assessment problems and public issues during the interviews neither of these interpretations seems particularly illuminating. Instead, our analysis has examined the researchers' struggles to identify issues as revealing the partialities of our experiment in creating critical proximity between the assessment researchers and the assessment's publics. Where the visualisations had been designed to present the researchers with a heterogeneous view of the topic of their research, the ease with which some interview participants distanced their research from the topics raised in the visualisations we assembled suggests that digital methods can (potentially at least) just as easily be deployed to create distance as proximity between assessments and their publics.

Finally, then, digital methods research is not only a domain of methodological experimentation but is an approach relevant to questions about how assessments of controversial topics, like CDR, gain legitimacy in digital societies as *scientific* assessments. STS research has long highlighted the epistemic ambiguity of knowledge produced by assessments of climate change (Jasanoff et al., 1998), which is arguably amplified in assessments of topics like CDR (Beck and Mahony, 2018). Yet, as our analysis highlights, such epistemic ambiguities did not necessarily manifest explicitly in the interview participants' engagement with the visualisations. Indeed, for some researchers, the visualisations appeared to provide an empirical basis for demarcating scientific from non-scientific issues, enabling them to *dis*engage from the problem of the interdisciplinary assessment's public. Despite platforms like Twitter being a site where scientists frequently post and engage with each other, the traces of interaction recorded may, it seems, easily be dismissed as having little or no relevance for the practice of scientific assessment. In the interviews we find controversy most clearly detectable in the divergent justifications offered for otherwise common appraisals of the visualisations (e.g. the most retweeted BECCS post). This finding makes clear why attempts to evaluate public debates on platforms based on analysis of data

collected from APIs alone may fail to sufficiently engage with the multivalence of digital records, the competing ways in which platforms are discursively constructed as sites of engagement and the situations in relation to which expressions on them gain public relevance (Marres, 2015). Submitting the question of Twitter's public relevance to participatory inquiry, our study highlights both the value of an interactive method like interviewing to detecting traces of controversy as well as some of the different ways in which (digitally-mediated) controversy comes to be framed out assessment processes. While the researchers' engagements with the visualisations aggregated from tweets about afforestation and BECCS may not have yielded a slate of CDR-related issues amenable to expression in propositional form or thematic differentiation, the interviews demonstrated that such visualisations hold potential for facilitating discursive interaction and reflexivity between interdisciplinary researchers, surfacing divergent imaginaries of assessments and their publics. Far from breaking with qualitative research traditions in STS, we suggest that experiments such as ours demonstrate the value of mixed 'quali-quantitative' approaches (Moats, 2021) for controversy analysis and practicing critique through participatory inquiry.

Acknowledgments

The authors gratefully acknowledge the participation of, and discussions with, colleagues involved on the project Feasibility of Afforestation and Bioenergy with Carbon Capture and Storage for Greenhouse Gas Removal. An early version of this paper was presented at the 4S/EASST 2020 meeting, hosted by Institute of Sociology of the Czech Academy of Sciences. The authors benefited much from discussions in a seminar hosted by the Science, Society and Sustainability (3S) research group at the University of East Anglia. We also wish to thank the two anonymous reviewers for helping clarify the final analysis. The Natural Environment Research Council funded the research reported on in this paper (grant number: NE/P019951/1). The research also benefited from UK Energy Research Centre (UKERC) Phase 4 funding (EPSRC grant reference EP/S029575/1).

References

Beck S and Mahony M (2018) The IPCC and the new map of science and politics. *WIREs Climate Change* 9(6): e547. DOI: 10.1002/wcc.547.

Bellamy R and Lezaun J (2017) Crafting a public for geoengineering. *Public Understanding of Science* 26(4): 402–417. DOI: 10.1177/0963662515600965.

Biofuelwatch (2020) *Great columm from @Richard_Dixon on #bioenergy with carbon capture & storage: ""BECCS as an idea [...] has a terrible reputation, mainly because of the huge areas of land that would be needed [...], but also because, done wrong, BECCS would actually make climate change worse."* 🌳🔥 19 March [Twitter]. Available at: https://twitter.com/biofuelwatch/status/1240747238143545348 (accessed 7.3.2022)

Callon M, Lascoumes P and Barthe Y (2009) *Acting in an Uncertain World: An Essay on Technical Democracy*. Cambridge, MA: MIT Press.

Callon M, Law J and Rip A (1986) Qualitative scientometrics. In: Callon M, Law J and Rip A (eds) *Mapping the Dynamics of Science and Technology*. Hampshire, UK: Palgrave Macmillan Press, pp. 103–123.

Cox E, Spence E and Pidgeon N (2020) Public perceptions of carbon dioxide removal in the United States and the United Kingdom. *Nature Climate Change*. Nature Publishing Group: 1–6. DOI: 10.1038/s41558-020-0823-z.

Chilvers J and Kearnes M (2016) *Remaking Participation: Science, Environment and Emergent Publics*. Abingdon: Routledge.

Chilvers J, Pallett H and Hargreaves T (2018) Ecologies of participation in socio-technical change: The case of energy system transitions. *Energy Research & Social Science* 42: 199–210.

Darier É, Gough C, Marchi BD, et al. (1999) Between democracy and expertise? citizens' participation and environmental integrated assessment in Venice (Italy) and St. Helens (UK). *Journal of Environmental Policy and Planning* 1(2): 103–120.

Dawson P (2018) *Trying to tackle climate change by replacing forests with crops for bioenergy power stations that capture carbon dioxide (CO2) could instead increase the amount of CO2 in the atmosphere, scientists say. #ActOnClimate #ClimateChange https://t.co/pDqDFkSzOI*. 18 December [Twitter]. Available at: https://twitter.com/pauledawson/status/1071644863307886592 (accessed 7.3.2022).

Forster J, Vaughan NE, Gough C, et al. (2020) Mapping feasibilities of greenhouse gas removal: Key issues, gaps and opening up assessments. *Global Environmental Change* 63: 102073. DOI: 10.1016/j.gloenvcha.2020.102073.

Geden O (2016) The Paris Agreement and the inherent inconsistency of climate policymaking. *WIREs Climate Change* 7(6): 790–797. DOI: https://doi.org/10.1002/wcc.427.

Gilbert GN, Gilbert PN and Mulkay M (1984) *Opening Pandora's Box: A Sociological Analysis of Scientists' Discourse*. Cambridge, UK: Cambridge University Press.

Guston DH (2014) Understanding 'anticipatory governance'. *Social Studies of Science* 44(2): 218–242. DOI: 10.1177/0306312713508669.

Hulme M (2009) *Why We Disagree about Climate Change: Understanding Controversy, Inaction and Opportunity*. Cambridge, UK: Cambridge University Press.

IPCC (2014) *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Geneva, Switzerland: IPCC. Available at: https://www.ipcc.ch/report/ar5/syr/ (accessed 9 July 2020).

Irwin A and Michael M (2003) *Science, Social Theory & Public Knowledge*. Maidenhead, UK: McGraw-Hill Education (UK).

Jacomy M, Venturini T, Heymann S and Bastian M (2014) ForceAtlas2, a continuous graph layout algorithm for handy network visualization designed for the Gephi software. *PLOS ONE* 9(6). DOI: 10.1371/journal.pone.0098679.

Jasanoff S (2003) Technologies of humility: Citizen participation in governing science. *Minerva: A Review of Science, Learning & Policy* 41(3): 223-244.

Jasanoff S, Wynne B, Buttel F, et al. (1998) Science and decision-making. In: Rayner S and Malone E (eds) *Human Choice and Climate Change, Vol 1: The Societal Framework*. Ohio: Battelle Press, pp. 1–87.

Kasemir B, Dahinden U, Swartling ÅG, Schüle R, Tabara D and Jaeger CC (2000) Citizens' perspectives on climate change and energy use. *Global Environmental Change* 10(3): 169–184. DOI: 10.1016/S0959-3780(00)00022-4.

Lezaun J, Marres N and Tironi M (2016) Experiments in participation. In: Felt U, Fouché R, Miller CA and Smith-Doerr L (eds) *The Handbook of Science and Technology Studies*. Cambridge, MA: MIT Press, pp. 195–219.

Low S and Schäfer S (2020) Is bio-energy carbon capture and storage (BECCS) feasible? The contested authority of integrated assessment modeling. *Energy Research & Social Science* 60: 101326. DOI: 10.1016/j.erss.2019.101326.

Madsen AK and Munk AK (2019) Experiments with a data-public: Moving digital methods into critical proximity with political practice. *Big Data & Society* 6(1): 2053951718825357. DOI: 10.1177/2053951718825357.

Markusson N, McLaren D and Tyfield D (2018) Towards a cultural political economy of mitigation deterrence by negative emissions technologies (NETs). *Global Sustainability* 1. Cambridge University Press. DOI: 10.1017/sus.2018.10.

Marres N (2015) Why map issues? On controversy analysis as a digital method. *Science, Technology, & Human Values* 40(5): 655–686.

Marres N and Moats D (2015) Mapping controversies with social media: The case for symmetry. *Social Media and Society* 1(2): 1-17. DOI: 10.1177/2056305115604176.

Moats D (2021) Rethinking the 'Great Divide': Approaching interdisciplinary collaborations around digital data with humour and irony. *Science & Technology Studies* 34(1): 19-42.

Nemet GF, Callaghan MW, Creutzig F, et al. (2018) Negative emissions—part 3: Innovation and upscaling. *Environmental Research Letters* 13(6). IOP Publishing: 063003. DOI: 10.1088/1748-9326/aabff4.

Pearce W, Niederer S, Özkula SM and Sánchez Querubín N (2019) The social media life of climate change: Platforms, publics, and future imaginaries. *Wiley Interdisciplinary Reviews: Climate Change* 10(2): e569. DOI: 10.1002/wcc.569.

Pielke R (2007) *The Honest Broker: Making Sense of Science in Policy and Politics*. Cambridge, UK: Cambridge University Press.

Rieder B and Borra E (2014) Programmed method: developing a toolset for capturing and analyzing tweets. *Aslib Journal of Information Management* 66(3): 262–278. DOI: 10.1108/AJIM-09-2013-0094.

Rogers R (2013) *Digital Methods*. Cambridge, MA: MIT Press.

Stilgoe J, Owen R and Macnaghten P (2013) Developing a framework for responsible innovation. *Research Policy* 42(9): 1568–1580. DOI: 10.1016/j.respol.2013.05.008.

Stirling A (2008) "Opening up" and "closing down": Power, participation, and pluralism in the social appraisal of technology. *Science, Technology, & Human Values* 33(2): 262–294. DOI: 10.1177/0162243907311265.

Tansey J, Carmichael J, Van Wynsberghe R and Robinson J (2002) The future is not what it used to be: Participatory integrated assessment in the Georgia Basin. *Global Environmental Change* 12(2): 97–104. DOI: 10.1016/S0959-3780(02)00011-0.

van Asselt Marjolein BA and Rijkens-Klomp N (2002) A look in the mirror: Reflection on participation in integrated assessment from a methodological perspective. *Global Environmental Change* 12(3): 167–184. DOI: 10.1016/S0959-3780(02)00012-2.

van der Sluijs JP (2002) A way out of the credibility crisis of models used in integrated environmental assessment. *Futures* 34(2): 133–146. DOI: 10.1016/S0016-3287(01)00051-9.

van der Sluijs J, van Eijndhoven J, Shackley S and Wynne B (1998) Anchoring devices in science for policy: The case of consensus around climate sensitivity. *Social Studies of Science* 28(2): 291–323. DOI: 10.1177/030631298028002004.

Vaughan NE and Gough C (2016) Expert assessment concludes negative emissions scenarios may not deliver. *Environmental Research Letters* 11(9): 095003. DOI: 10.1088/1748-9326/11/9/095003.

Venturini T (2010) Diving in magma: how to explore controversies with actor-network theory. *Public Understanding of Science* 19(3): 258–273. DOI: 10.1177/0963662509102694.

Waller L, Rayner T, Chilvers J, et al. (2020) Contested framings of greenhouse gas removal and its feasibility: Social and political dimensions. *Wiley Interdisciplinary Reviews: Climate Change* 11(4): e649.

Waller L, Rayner T and Chilvers J (2021) Searching for a public in controversies over carbon dioxide removal: An issue mapping study on BECCS and Afforestation. *Science, Technology, & Human Values*. Epub ahead of print 27 September.DOI: 10.1177/01622439211043568.

Wynne B (2007) Public participation in science and technology: performing and obscuring a political–conceptual category mistake. *East Asian Science, Technology and Society: An International Journal* 1(1): 99–110.

Notes

1 We elaborate the concept of digital traces in the following section.

2 Tweets were collected using the DMI-TCAT software (Rieder and Borra, 2014) which connects to Twitter's Streaming API. Lists of query terms for each dataset and tweet IDs are available in the supplementary material.

3 The interdisciplinary assessment in which this research was undertaken focused on assessing the "real-world feasibility" of afforestation and BECCS, linked to a specific funding programme on greenhouse gas removal. See: https://www.ukri.org/our-work/browse-our-areas-of-investment-and-support/greenhouse-gas-removal-from-the-atmosphere/ (accessed 17/03/2022).

4 These materials can be made available on request.

5 Table2Net software developed by Science Po's medialab, available at: https://medialab.github.io/table2net/ (accessed 04/01/2021).

6 Mini-VAN software, created by the Public Data Lab, can be accessed here: https://minivan.publicdatalab.org/ (accessed 04/01/2021).

7 Our initial research design had proposed to engage participants in face-to-face analysis of the network visualisations. Due to the Covid-19 pandemic, the research design was adapted to an online environment.

8 Spaces were included in the query to avoid returning results such as Poland, Iceland etc.

9 For this reason, in what follows we use the term "visualisations" to refer to both the aggregated lists in the dossier and to the co-hashtag networks.

10 This list of hashtags has been edited to remove those resulting from a query error during the first two months of data collection and therefore is not identical to that provided to the participants.

11 All participants asked this question answered: "no". Two participants were not asked this question.

12 Antagonistic modes of engagement have been widely valued for bringing to light the more controversial dimensions of technical topics and contributing to processes of issue formation (see discussion in Callon et al., 2009; Lezaun et al., 2016; Pielke, 2007).