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The social media life of climate change: platforms, publics and future imaginaries. <https://doi.org/10.1002/wcc.569>

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ABSTRACT

Social media is a transformative digital technology, collapsing the “six degrees of separation” which have previously characterized many social networks, and breaking down many of the barriers to individuals communicating with each other. Some commentators suggest that this is having profound effects across society, that social media have opened up new channels for public debates and have revolutionized the communication of prominent public issues such as climate change. In this article we provide the first systematic and critical review of the literature on social media and climate change. We highlight three key findings from the literature: a substantial bias toward Twitter studies, the prevalent approaches to researching climate change on social media (publics, themes, and professional communication), and important empirical findings (the use of mainstream information sources, discussions of “settled science,” polarization, and responses to temperature anomalies). Following this, we identify gaps in the existing literature that should be addressed by future research: namely, researchers should consider qualitative studies, visual communication and alternative social media platforms to Twitter. We conclude by arguing for further research that goes beyond a focus on science communication to a deeper examination of how publics imagine climate change and its future role in social life.

1 INTRODUCTION

The explosion of social media over the last 10 years has provided fertile ground for social scientists for three key reasons. First, the rapid emergence of social networking sites and platforms have gripped the public imagination, providing a strong public interest motivation for conducting research in this area. Second, and more substantively, social media have troubled established hierarchies of communication, eroding the power of traditional gatekeepers such as large media companies, political parties, and scientific organizations and journals while elevating the potential of individuals to reach large numbers of people as never before. Third, social media produce and provide large volumes of data that are readily amenable to analysis by social scientists. The availability of this data varies between

different social media platforms and over time as the private companies who own the platforms change their policies, and accordingly, their APIs (application programming interfaces) (Rieder, 2016). Researchers working with platforms that offer access to data through their APIs, such as Twitter, can quickly and easily download social media posts filtered by criteria such as keyword, user name, and geolocation using one of many freely available research tools (e.g., Borra & Rieder, 2014; Thelwall, 2018). In principle, this provides a new means of gauging public opinion alongside well-established methods such as opinion polling, with some researchers going so far as to describe social media posts as a “proxy” for wider public discourse (Kirilenko, Molodtsova, & Stepchenkova, 2015, p. 94). This journal has already published comprehensive and critical reviews of the broad field of climate communication (Moser, 2010; Nerlich, Koteyko, & Brown, 2010; Pearce, Brown, Nerlich, & Koteyko, 2015; Schäfer, 2012). However, none of these reviews focused specifically on social media platforms as sites for climate communication, despite commentators calling for greater engagement with social media by climate scientists (Hawkins, Edwards, & McNeill, 2014) and the IPCC (Hickman, 2015). In this Advanced Review, we address this gap by providing the first systematic and critical review (Hulme, 2018) of the “burgeoning literature” on social media and climate change (Pearce et al., 2015). We identify the extent of the literature and its distribution across different social media platforms, the approaches to social media taken by researchers, the key empirical findings from the literature, and the most important gaps in the literature that require addressing by future research. In doing so, we seek to apply insights from the critical social media literature to climate change communication, illuminating the strengths and weaknesses of the extant research and illuminating fruitful future paths for research in this important field of research.

2 METHODOLOGY

2.1 Search protocols

To collect relevant literature, starting points for the queries were the keywords “climate change” and “global warming,” the latter being included to reflect its prominence in the United States where it is sometimes used as a synonym for climate change (Schuldt, Konrath, & Schwarz, 2011). The two search terms were supplemented with a list of social media keywords, including synonyms for social media drawn from existing literature (e.g., digital media, new media, and social networking sites), the names of individual social networking platforms (such as Facebook and Twitter), and a few other types of social media (e.g., blogs, vlogs, and mobile apps). The individual platforms were drawn from an industry report published by We Are Social detailing the most popular social media platforms (Kemp, 2017, p. 46). We note that as scholarly literature is largely written in the English language, existing studies may lean toward platforms prominent in English-speaking countries. We sought to partially mitigate this potential bias by including platforms prominent in other countries in our search terms (see Supporting Information Table S1). We chose 2005 as the

starting date for our review, reflecting the emergence of many prominent social media platforms and smartphone technologies (Hands, 2011).

2.2 The sample

In January 2018, we ran three sets of queries on the Scopus database: (a) synonyms, (b) individual platforms, (c) other types of social media and apps (as outlined above). This initial search returned a total of 533 articles. Articles were excluded when they met any of the following criteria: (a) social media constituted a relatively minor part of the empirical or theoretical work of the article, (b) climate change or global warming did not constitute a key subject of the article, or (c) the origins and/or publication status of the article were obscure. This produced a sample of 59 papers. The Scopus search was complemented with a more focused query of Google Scholar. This increased the total collection of articles to 70, which we read closely to identify those articles with a strong focus on social media platforms as sites for climate change communication, resulting in a final corpus of 35 articles for review (see Supporting Information Table S1 for detail on the searches conducted on Scopus and Google Scholar).

An initial analysis by platform showed the literature collection to be dominated by Twitter studies, with a small selection covering Facebook, YouTube, and cross-platform studies (see Table 1). This was surprising considering the vast distribution and popularity of other social media platforms outlined earlier (Kemp, 2017). Compared with global popularity data, the distribution of platforms suggests a bias toward social media platforms popular with English-speaking publics, with platforms such as QZone, VKontakte, and Odnoklassniki not featuring in the articles we analyzed (Cosenza, 2018). While some of that bias may be attributed to the language of the queries, the literature also fails to reflect broader social media trends within English-speaking countries. For example, according to the Pew Research Center's 2018 data (Smith & Anderson, 2018), most Americans favor Facebook and YouTube over Twitter, while young adults lean toward Snapchat and Instagram, neither of which appear in this corpus of literature. This is important because social media, while often discussed in general terms, is not a homogeneous category. Rather social media contains many different “platform cultures” arising from a combination of technical aspects and user behaviours (see Box 1).

Table 1. Social media platforms: Numbers of active users compared with prevalence in climate change literature. Source: Kemp (2017).

| Social media platform by active users | Monthly active user accounts (millions) | Articles in the literature that include platform (up to January 2018) |
|----------------------------------------------|------------------------------------------------|------------------------------------------------------------------------------|
| Facebook | 1,871 | 5 |
| Youtube | 1,000 | 3 |

| | | |
|-------------|-----|----|
| Qzone | 632 | 0 |
| Instagram | 600 | 0 |
| Tumblr | 550 | 0 |
| Twitter | 317 | 28 |
| Baidu Tieba | 300 | 0 |
| Sina Weibo | 297 | 1 |

BOX 1. THE CULTURES OF SOCIAL MEDIA PLATFORMS

While Twitter provides significant opportunities for social media researchers, particularly in the form of textual analysis, other hugely popular platforms such as YouTube and Instagram remain understudied. This is important because of the different “platform cultures” that exist within social media; that is, the diverse vernaculars that arise from a combination of the user practices and technical affordances at play within any given digital medium (Gibbs et al., [2015](#)). Similar-looking digital objects can assume different roles depending on the platform. For example, hashtags are key objects which organize content on both Twitter and Instagram, but Instagram’s relative lack of constraints on hashtag usage enable far greater cross-pollination of content and conversations than is possible on Twitter (Rogers, [2017](#)).

Such affordances call attention to the prestructured ways in which content is organized and the “attention economies” that shape climate communication and engagement with publics. For example, the Twitter content that is most engaged with may be that which is most amenable to sharing, rather than that deemed to be the most relevant by climate change experts. However, this should not be seen as a limitation. Platforms are active environments that engineer sociality (Marres, [2017](#)). The relevance of such an approach has previously been developed in the study of online climate change controversy and issue-mapping prior to social media (Rogers & Marres, [2000](#)), so we argue that social media researchers should attempt to find ways past data limitations in order to research across different social media platforms, thereby revealing the different platform cultures that shape and serve the communication of climate change.

In what follows we will therefore first address how social media, and particularly Twitter, is approached by researchers as a site for climate change publics, a forum for climate change issues, and a means to study professional communication. We then provide an overview of the knowledge produced on climate change through social media investigations, including analysis of information sources, the framing of climate change as “settled science,”

polarization and echo chambers, and relationships between social media content and temperature anomalies.

3 APPROACHES: HOW IS TWITTER RESEARCHED?

In the core climate communication research literature that was reviewed, we identify three distinct approaches to studying Twitter. Each of these coexisting and overlapping approaches advocates particular ways in which Twitter can be repurposed for research.

3.1 Climate change publics

In the first type of study, Twitter is described as a digital forum where publics seek out and discuss scientific issues (Anderson & Huntington, 2017). Here, Twitter-oriented research offers opportunities for capturing “users' knowledge of and views on issues like climate change” (Auer, Zhang, & Lee, 2014, p. 291; Cody, Reagan, Mitchell, Dodds, & Danforth, 2015; Williams, McMurray, Kurz, & Lambert, 2015). Indeed, the literature describes Twitter both as a widely used platform and a source for climate change information-exchanges which has become “too important now to ignore” (Veltri & Atanasova, 2017, p. 724). Twitter's broad user-base provides researchers with the opportunity to capture distinct, contradictory, and marginal views regarding climate change; a site where the different sides of a debate can be studied and that provide a continuous “picture of current public sentiment” (McKinnon, Semmens, Moon, Amarasekara, & Bolliet, 2016, p. 2), for example, in the study of “climate skeptics” (Holmberg & Hellsten, 2016a). Moreover, as Twitter is used in a large number of countries it may also serve to capture a diversity of cultural perspectives about climate change, including those “from the global south” (Bosch, 2012, p. 45) and from countries which have attracted less scholarly attention. Here for example, Twitter can also be studied in relation to a local platform such as Weibo, in China (Riley, Wang, Wang, & Feng, 2016).

Opinions may be captured as it “is now possible to empirically analyze online conversations that are voluntarily generated and shared by users” (Jang & Hart, 2015). Here Twitter is repurposed as a “snapshot machine” in which the research may describe the state of the art in public debate, lending itself to both small-scale and “big data” studies. A recurring way of operationalizing this approach is to look at the top users for a particular subissue, who are also referred to as opinion leaders, (micro-)celebrities, “evangelists” (Cha, Benevenuto, Haddadi, & Gummadi, 2012), or “influencers” (Abidin, 2015), in order to make sense of the reach, spread, resonance, and lifespan of a message or campaign based on who broadcasts it. Several studies follow such top users after important official United Nations climate change events, such as a Conference of the Parties (COP) or the publication of an IPCC report (Holmberg & Hellsten, 2016a, 2016b; Newman, 2017; O'Neill, Williams, Kurz, Wiersma, & Boykoff, 2015; Pearce, Holmberg, Hellsten, & Nerlich, 2014; Walter, De, &

Bruggemann, 2017). Pearce et al. (2014) for instance look at the “community dynamics” of tweets around the publication of the 2013 IPCC report, and look at the role that “evangelists” (e.g., opinion leaders, celebrities, influencers) play in reaching further-removed publics. Newman (2017) studies which Twitter users, tweets, and media sources attracted the most attention after the release of the IPCC's Fifth Assessment Report Summary for Policymakers. O'Neill et al. (2015) study the tweets of the top 50 users in their data set but do not distinguish between types of users and whether they are individuals, companies, media outlets, or automated accounts (bots). Jacques & Knox (2016, p. 835) explicitly describe their study of climate change skepticism as a mixed method approach, referring to it as “a bridge between large and small data, selecting skeptical discourses out of thousands of messages from thousands of general users in order to understand how individual broadcasters relate to larger social forces.”

3.2 Climate change themes

In a second type of study, the features offered by Twitter are framed in relation to the platform's capacity to generate thematic data sets, with hashtags or keywords being a common entry point. In this approach, Twitter is a platform to be queried, as it hosts data that can be captured and mined as well as text that can be analyzed with the help of computational techniques. In this realm, the platform is described as an exciting source for “observational data,” “real-time responses” (Kirilenko et al., 2015) and nonintrusive data (Kirilenko, Desell, Kim, & Stepchenkova, 2017). Prominent in this type of study are questions that ask what type of data or unit of analysis a tweet represents. For instance, tweets are seen as “political texts,” privileging longitudinal analysis but also the capturing of emerging themes, and as sources to study sentiment (Reed, 2016).

These studies take up the medium-specific characteristics of Twitter as means for analysis, such as @mentions, hashtags, retweets, or the geographic location of tweets or users. From the above-mentioned features, hashtags (user-generated topic markers) are approached as an important organizing principle in Twitter (Small, 2011). Hashtags are studied to trace and monitor their uptake and life-span during or after an event, publication, campaign, or even following an extreme weather event (in the case of Anderson & Huntington, 2017). Network analysis of either co-hashtags (hashtags mentioned alongside other hashtags) or hashtag-user networks (consisting of hashtags and the users who mention them) offers ways to retrieve influence and spread, for instance, by looking at issue coupling (or hashtag hijacking) or tracking issue attention over time. For example, Williams et al. (2015) combine data from five different hashtags around climate change and global warming and uses the data to create three networks for each hashtag, clustered by followers, retweets and @mentions. This approach is useful to identify different subcommunities organized by the use of specific hashtags. In this case, the researchers found that the hashtag for anthropogenic global warming, #agw, has much larger skeptics' presence than the hashtags #climatechange or #globalwarming. Another use of hashtags that falls into (the

operationalization of) this type of study is using them to trace the changing attention to issues as a temporal analysis, in which the scholars identify peaks, look at real-time data streams or conduct a daily analysis of a particular discussion for a set period of time.

The limitations of the data sets are often expressed in relation to the limitations of the API offering only partial access to the data. In this approach, large sets of tweets are often collected, and are used for semantic network analysis, topic modeling, or sentiment analysis. Many of the selected papers combine quantitative and qualitative approaches to Twitter as a dataset. For example, McKinnon et al. (2016) conduct a big data analysis of 647,539 tweets, excluding the retweets, and manually code the data for further content analysis.

3.3 Climate change professional communication

Where the first type of study foregrounded the users, the second looked more at themes and sentiments using Twitter data. In a third type of account, Twitter is used to provide a reflexive view on social media use by professionals in the field of climate change communication. Here, Twitter offers an opportunity to understand campaign dynamics and collect insights with which to fine tune one's own communication strategies. For example, the ways in which “ICT platforms such as social media have been adapted by individuals and groups for use in climate change activism” (Titifanue, Kant, Finau, & Tarai, 2017, p. 135) education, and engaging publics are highlighted. Indeed, Twitter allows communication science researchers to monitor publics and evaluate the success of their activities. One may also study the social media activity of scientists during climate change events, offering a window into professional activities and the resonance of the individual actors. Concepts from online activism such as “connective action” are featured in this type of account (Bennett & Segerberg, 2012), as are enquiries into the “networking mechanisms” (Segerberg & Bennett, 2011), “hashtag hijacking” (Bode, Hanna, Yang, & Shah, 2015; Christensen, 2013), and “conversational links” (Pearce et al., 2014) of professional or activist groups.

4 FINDINGS: WHAT DO WE KNOW ABOUT CLIMATE CHANGE ON SOCIAL MEDIA?

The previous section took a “meta” approach to reviewing the literature, identifying three different research approaches to studying climate change communication on social media. The following section takes a more detailed view of four key empirical findings in the literature: information sources used on social media, the use of the “settled science” frame in social media posts, tendencies toward polarization and echo chambers, and the relationship between social media content and temperature anomalies.

4.1 Information sources and influential users

Social media platforms are often argued to have disturbed media power structures, reducing the influence of mainstream media organizations and allowing non-elite actors to play a much greater role in shaping public debate, to the extent that social media is portrayed as central to recent concerns over “fake news” (Herzog, 2016). Despite these worries, the available literature (while limited) provides a consistent picture of mainstream media sources remaining prevalent in Twitter climate change communication. Studying the 2013 IPCC report, Newman (2017, pp. 821–822) finds that within the “100 most frequently occurring domain names” 35% were mainstream media (e.g., CNN, The Washington Post, The Atlantic), 23% were new media (e.g., BuzzFeed, Huffington Post, or other blogs), 20% were science news (e.g., Nature, Scientific American), 12% were government or academic, and 9% were advocacy sites. A study of a random week on Twitter (not around a major news event), found “little ecological diversity of sources from the World Wide Web” with 67% of web links on climate change going to “professional news organisations” (Veltri & Atanasova, 2017, p. 733). A larger study across 2012 again found a similar pattern, the Guardian being the most frequently referenced single domain (5% of tweets containing hyperlinks), followed by the Huffington Post (3%) and Think Progress (2.2%). In comparison, the most prevalent blogs not attached to a mainstream news organization were the climate skeptic blogs Watts Up With That and Climate Depot (0.2% each) (Kirilenko & Stepchenkova, 2014). While suggesting an overall lack of prominence for nonelite climate skeptic sources on Twitter, the 2012 data also show spikes in interest for such information when featured in the mainstream media. Two of the most discussed climate news events on Twitter were from the Daily Mail (a mainstream news source), relating to the so-called pause in global warming since 1997 and framing this as a reason to cast doubt on scientific projections of increasing global temperature (Hawkins et al., 2014; Hollin & Pearce, 2015; Medhaug, Stolpe, Fischer, & Knutti, 2017; Roberts, Palmer, McNeall, & Collins, 2015).

While the external sources being referred to on Twitter are typically mainstream, influential users come from more diverse sources. Newman (2017, p. 818) analyzed the 100 most retweeted posts around the 2013 IPCC report, finding that 35% of the tweets came from non-elite users unaffiliated with any scientific, media, or nonprofit organization, followed by media (17%) and advocacy organizations (16%). Individual scientists accounted for 7% of the total. However, the retweet network distribution was heavily skewed toward the largest number of retweets, and among the top five retweets there were no non-elite users. There remains limited evidence in the literature, but it appears that while mainstream information sources are dominant, the distribution and diversity of influential users on Twitter is a more complicated picture which requires further research.

4.2 Settled science

A familiar theme in the wider climate change literature is the extent to which debates about climate change are reduced to debates about climate science, downplaying political discussions about what should be done regarding climate mitigation and adaptation (Latour,

2017; Sarewitz, 2011). Critical social scientists have long argued that focusing on climate science over climate politics prolongs, rather than cauterizes, debates over whether climate science is “settled” or “sound” (Demeritt, 2001; Pearce et al., 2017a, 2017b). The reverberations of this phenomenon have been identified on social media. For example, O'Neill et al. (2015) studied coverage of the IPCC Fifth Assessment Report (AR5) across print media, broadcast media, and Twitter, quantitatively and qualitatively comparing coverage of the three Working Group (WG) reports. They found that physical science was given a privileged position in Twitter debates in two ways. First, the quantity of Twitter activity was greatest, both in terms of number of tweets sent and number of active users, in the report focused on physical science (WGI) and tailed off through WGII (climate impacts) and WGIII (climate policies). Here, Twitter was consistent with broader patterns of media coverage; both print and broadcast media gave the most coverage to WGI. The authors identified possible reasons for this including “story fatigue” as the IPCC works through the release of its WG reports, more media-friendly communication of WGI, and the absence of well-developed narratives around WGIII. Second, O'Neill et al. found the dominant frame for Twitter discussions of the IPCC reports to be “settled science,” focusing on the “broad expert consensus” of climate science and quashing of uncertainty. This was the case across all three WGs, not just WGI focused on physical science. The reasons for this are unclear but suggest that climate activists and other “pro-action” Twitter users took the opportunities presented by the IPCC WG reports to defend climate science against attacks, whether or not the report itself was focused on climate science.

4.3 Polarization and echo chambers

Polarization has long been a subject of interest in the climate change literature, with scholars noting the presence of political polarization about the topic (Antonio & Brulle, 2011; Hart & Nisbet, 2012; Kahan et al., 2012; Whitmarsh & Corner, 2017). Similarly, polarization has been a persistent theme in the social media literature (Anderson, Brossard, Scheufele, Xenos, & Ladwig, 2014; Bessi et al., 2016; Gruzd & Roy, 2014; Yardi & Boyd, 2010), so it is no surprise that a number of scholars have focused on climate change polarization on social media. The most detailed treatment of the topic comes from Williams et al. (2015), who use network analysis to investigate segregation and interaction between communities of Twitter users, categorizing users as activist, skeptic, neutral, unknown, ambiguous or unclassified according to tweet content. They found high levels of polarization and a tendency for active users (either skeptic or activist) to have strong attitudes, leading them to conclude that Twitter climate change discussions are “characterised by strong attitude-based homophily and widespread segregation of users” (p.135) into like-minded communities. The authors also found some mixed-attitude communities where users with opposing views did interact. These findings echoed Pearce et al.'s study of Twitter use around the publication of AR5 WGI (2014), which found that while users had “significantly more conversational connections with likeminded people than others” (p. 8), there was also

a highly connected mixed-attitude community focused around UK users. The authors argued this offers “grounds for cautious optimism” (p. 9) regarding future interactions between polarized groups but did not analyze the qualitative content of these interactions. Williams et al. (2015) found that users within such mixed-attitude communities were less polarized, and that when activists and skeptics outside such communities engaged in outgroup engagement, they tended to express more negative sentiment. Interestingly, Williams et al. found similarities between the behavior of activists and skeptics, with no substantive differences in homophily, outgroup engagement and partisan sentiment. They also found that activists were more active communicators than skeptics, with a greater potential audience reach.

Building on these findings about negative sentiment, recent research has found a persistent presence of both incivility and sarcasm in climate change communication on Twitter (Anderson & Huntington, 2017). The article finds these characteristics to be more associated with climate skepticism, although the reasons for this are unclear. It may be a discursive strategy employed by climate skeptics who find themselves in a “hostile opinion environment” (Anderson & Huntington, 2017, p. 613), or it may be related to a greater level of outgroup engagement (which is likely to be negative) from climate skeptics than activists (Williams et al., 2015). Whatever the reason, more research into the dynamics within and between groups, and the manifestation of these dynamics within Twitter conversations, would be beneficial to increasing our understanding of the role of civility in climate change communication. In particular, there is potential for building on recent research into the links between civility and skepticism to explore the role of social media in fostering or hindering trust within climate change discussions (Ramírez-i-Ollé, 2015, 2018).

Homophily and incivility are often rolled into broader discussions about the prevalence of social media “echo chambers,” commonly portrayed in the media as a pejorative phenomenon (e.g., Floridi, 2016; Grimes, 2017). However, the coming together of like-minded people online can be positive for social movements, enabling them to “craft and amplify their own narrative, to reach out to broader publics, and to organize and resist” (Tufekci, 2017, p. xxix). On open platforms such as Twitter, which break down many of the barriers to individuals communicating with each other (Bakhshandeh, Samadi, Azimifar, & Schaeffer, 2011), the complexity of the social world is laid bare. If individuals using the platform are to develop simplified, coherent versions of that world on which to base action then it is unsurprising, and indeed logical, that Twitter users should limit the amount of “uncomfortable knowledge” appearing in their newsfeeds from those with opposing views (Rayner, 2012). The unresolved question, and one worthy of further research, is around the conditions and characteristics under which this logical behavior becomes transformed into participation in the mixed-attitude communities associated with depolarization (Pearce et al., 2014; Williams et al., 2015).

Before leaving this subject, an important caveat should be placed on the research into polarization. Specifically, the coding schema used by both Pearce et al. (2014) and Williams et al. (2015) arguably have polarization “built in”; that is, they characterize views as supportive, unsupportive, or neutral with regards to climate science. If researchers categorize non-neutral users into only two opposing camps, it is unsurprising that a degree of polarization is discovered. So, while climate change social scientists are concerned about polarization, they may themselves be contributing to social imaginaries of polarization through their own research methods. Future research might take a more nuanced view of online climate change views by adopting more diverse categorizations; for example, as seen in Levy and Spicer's four “climate imaginaries” (Levy & Spicer, 2013) or work on the “Six Americas” of climate change (Maibach, Roser-Renouf, & Leiserowitz, 2009).

4.4 Responses to temperature anomalies

Social media scholars have noted how Twitter developed from a focus on “friend-following” to “event-following” (Rogers, 2013). As such, researchers have seized on the platform as a potential source of data about societal reactions to critical events related to climate change. This is particularly apposite as the twin problems of “invisible causes” and “distant impacts” have proved a persistent challenge for climate change communication (Moser, 2010). Hence, the emerging concept of Twitter users acting as “remote sensors” reacting to climate change events (Kirilenko & Stepchenkova, 2014) and potentially bridging the gap between abstract science and material consequences (Pearce et al., 2015).

One way this has been operationalized is through analyzing tweets in relation to temperature anomalies. Kirilenko et al. (2015) found that, in the United States, the rate of tweeting both at local and national levels was controlled by experience of such anomalies, and that this effect was not mediated by mass media coverage of the same anomalies. This big data approach is useful in identifying a macro-level pattern but, as the authors note, they did not study the content of the tweets so were unable to qualitatively analyze the links being made by Twitter users between temperature anomalies and climate change. For example, cold snaps may be described by some as being inconsistent with “global warming.” However, if it is generally accurate that climate activists are more active communicators than skeptics then we may expect such commentary to be a relatively minor part of the overall corpus of climate change tweets around temperature anomalies. Differences have also been found in the content of tweets related with “climate change” and “global warming”; the former being associated with environmental and political content, the latter being linked to weather (including heatwaves) and energy (Yeo et al., 2017). While there is considerable scope for more detailed research in this area, the notion of Twitter as a series of “remote sensors” is intriguing when set alongside attempts to develop the science of attributing extreme weather events to anthropogenic climate change.

Confidence that there has been an increase in heatwaves since the mid-20th century vary between different continents (IPCC, 2013, p. 210), although retrospective event attribution studies have shown “clear evidence” that human influence has increased the probability of extremely warm temperatures in many places (Stott et al., 2016). Peer-reviewed scientific research analyzing the extent of anthropogenic influence on particular extreme events such as heatwaves are typically published a number of months subsequent to the event, whereas the evidence from the social media literature suggests that the time of the heatwave itself is the ideal time to discuss climate change impacts and policies, before a scientific assessment of any anthropogenic element has been completed (Yeo et al., 2017). As discussed above, one of the challenges of climate change communication is the apparent invisibility of the phenomenon, a characteristic previously identified as a factor underlying public interest in the “extreme-weather-blame” question (Hulme, 2014). The evidence thus far shows that many social media users are not waiting for support from attribution science before discussing particular heatwaves in terms of climate change, suggesting that the relationship is becoming established as a social fact before scientific analyses of specific extreme events becomes available.

5 DISCUSSION

Our review highlights that the relationship between climate change and social media has received a lot of scholarly attention in recent years (particularly 2016–2017). Even so, much of that focus has been on individual social media platforms and forums, above all Twitter. This leaves ample scope for climate communication research on several social media platforms that have already proved fertile for studying other cases; for example, Instagram (Gibbs, Meese, Arnold, Nansen, & Carter, 2015), YouTube (O’Callaghan, Greene, Conway, Carthy, & Cunningham, 2015), and Facebook (Bessi et al., 2016). As much of this scholarly work is concentrated on big data analyses of text-based social media communications, there remain several avenues for further exploration. Here we map out three (intertwined) methodological approaches in the study of social media and climate change that warrant further scholarly investigation: (1) more detailed studies of climate change publics on social media, (2) inclusion of nontextual elements, and (3) single platform studies beyond Twitter and cross-platform studies that take into account the culture and agency of the platforms under study. We also identify one future area of empirical work that should be strengthened in the literature: critical research into climate imaginaries circulated by social media users.

5.1 More detailed study of publics

Earlier, we described how Twitter is a digital place and forum that is utilized to provide “snapshots” of lay audience communication through analyzing conversations and sentiment. In comparison, little attention has been given to the qualitative study of the role

of digital technologies in climate change communications. While some study has been dedicated to the exploration of digitally enabled activism practices around climate change (e.g., Askanius & Uldam, 2011; Greenwalt, 2016; Holmberg & Hellsten, 2015), there is considerable scope for more focused, qualitative studies of climate change in the literature. Existing literature centers on textual and communicative elements such as misinformation (Lawrence & Estow, 2017; Reed, 2016), opinion-leadership (Vraga, Anderson, Kotcher, & Maibach, 2015), argumentation (Walsh & McGowan, 2017), and media discourses (Koteyko, Jaspal, & Nerlich, 2013)—essentially the study of issues and their publics. Comparatively, little knowledge exists around individual online communities, hybrid (meaning online and offline) elements, and individual social media practices such as mobile usage, citizen collection of climate data, and non-textual user-generated contents—all areas that would benefit from alternative methodological approaches.

For example, following the social media practices of public figures could prove a fruitful alternative to keyword-related research around climate change. A comparison of public intellectuals with large followings can reveal differences in the ideas and scientific evidence promoted about climate change, as well as approaches to engagement and with those inside and outside of the network. Nisbet's (2014) identification of three groups of climate intellectuals—Ecological Activists, Smart Growth Reformers, and Ecomodernists—could act as a starting point for such research, to see if distinct climate imaginaries coalesce around these groups on social media platforms. Future research could also focus more specifically on climate scientists to investigate how they imagine scientific values such as objectivity can be maintained on social media platforms which thrive on polarization and conflict.

5.2 Visual communication

The core paper collection as well as the original larger collection contained almost entirely text-based studies. Although social media have been praised and acknowledged for being multimedia and multitextual, and although climate change is a phenomenon for which visual records have been significant, imagery, videos, and other nontextual elements have rarely been analyzed (Wang, Corner, Chapman, & Markowitz, 2018). To some extent, this can be attributed to the chosen platforms and foci in our sample. By and large, the core collection included big data Twitter studies. There is undoubtedly a methodological advantage in searching and analyzing text (rather than images) in big data studies due to the nature of currently available tools, as well as the traditional orientation of quantitative study. One of the core advantages of Twitter in particular lies in its medium-specific characteristics (e.g., @-mentions, hashtags, retweets, and location), its conversational and debate-oriented affordances, and thus the choice of the platform indirectly prioritizes a focus on textual elements. As yet, more visually oriented social media studies of climate change remain scarce. One exception is an experimental project we conducted at the University of Amsterdam's Digital Methods Initiative in July 2017 (Niederer, 2018; Pearce et al., 2018). In that project, we combined quantitative and qualitative approaches for cross-

platform analyses and visualizations of climate change imagery on social media. Our aim was to create more meaningful visual data as well as harness the potential of visual data on social media platforms. One of the findings from the project was that different platforms potentially lend themselves better for the study of visual content, and thus the choice of platform for scholarly investigation will necessarily influence the potential and inclusion of non-textual elements. There remains considerable potential in researching the visual communication of climate change through social media (see Box 2).

BOX 2. RESEARCHING VISUAL COMMUNICATION OF CLIMATE CHANGE ON SOCIAL MEDIA

Scientific organizations have begun to use bespoke infographics to communicate complex scientific information (e.g., Met Office Science, [2018](#)), while recent research has focused on evidence-based principles for the visual communication of climate change (Corner, Webster, & Teriete, [2015](#)). However, there is a significant gap in the literature around the use of climate visuals on social media (Wang et al., [2018](#)). The application of such principles to social media may require modification in relation to the existence of diverse platform cultures within social media (Box [1](#)). For example, different approaches to visual communication may be required on Instagram, a platform often associated with aesthetically attractive imagery, than on Tumblr, where memes and screenshots may be more prevalent. Researching the visual social media of climate change requires different interdisciplinary approaches depending on the scale involved (Pearce et al., [2018](#)).

First, images are more challenging than text to research at scale. New research tools such as Google Vision offer the potential for automatic recognition of elements of given images (Highfield & Leaver, [2016](#)). However, these tools are still in an early stage of development, and their utility for social scientists is yet to be proved, particularly whether or not the large volume of data the tools provide is capable of addressing key social science questions. Facilitating this will require effective interdisciplinary collaboration between computer science, sociologists and communication scholars (among others) in order to develop appropriate research methods and tools; including those that can capture embedded video and GIFs alongside still images. Second, deeper visual analysis of climate change imagery is possible using smaller data sets. This requires different interdisciplinary arrangements; notably, the inclusion of arts and humanities scholars with expertise in visual communication and aesthetics.

5.3 Platform studies beyond Twitter

As discussed in the methodology section above, Twitter is over-represented in the literature in comparison to its number of active users. We therefore propose that future research moves beyond Twitter to include (a) more visually oriented platforms, such as YouTube and Instagram, (b) platforms that allow for more in-depth investigations of individual communities—such as Facebook and LinkedIn,¹ and (c) social media platforms popular amongst non-English speaking publics, such as QZone, VKontakte, and Sina Weibo

(assuming that data collection is methodologically feasible). Exploratory studies for assessing such scope would therefore be particularly beneficial to the field, especially considering that climate change affects large areas of the global South. Additional advantages lie in studying issues across several platforms, as this would allow for comparative elements such as differing publics and platform affordance, and the reduction of “digital bias” through selectiveness online (Marres, 2017; Pearce et al., 2018).

5.4 Climate imaginaries

As discussed above, the empirical insights in the literature are largely drawn from big data studies, attempting to identify macro-level trends from large volumes of social media data. Yet such studies risk erase important context and meaning from social media posts (Pearce et al., 2015). A small body of literature exists which looks to derive more in-depth, qualitative insights from social media. In particular, there is an opportunity to investigate whether social media platforms provide space for subjective and normative imaginations of climate alongside the universal, apolitical climate imaginary proffered by science (Jasanoff, 2010). Such imaginaries are “collectively imagined forms of social life and social order” (Jasanoff & Kim, 2009, p. 120) marked by conversations and interactions “between fact-finding and meaning-making” (Jasanoff, 2010). However, such dynamics are hard to capture through automated big data studies. For example, the most sophisticated linguistic analysis of social media climate change communications comes from Veltri and Atanasova (2017, p. 735), who report that “the identification of themes and subthemes can be reliably obtained by automatic procedures...higher order structures of meaning...are much harder to automatically extract.”

This suggests that researchers must go beyond big data research in order to identify climate imaginaries circulating on social media. For example, Reed (2016) studies political communication by the United Kingdom Independence Party (UKIP) about renewable energy and climate change, employing critical discourse analysis to analyze a range of texts, including social media posts by key figures in the party. Reed places tweets in their political context, identifying UKIP's political strategy and charting the emergence of a particular imagination of the rural which precludes the development of renewable energy and doubts the findings of mainstream climate science. Riley et al. (2016) take a similar approach to a very different case; identifying the prevalence of an “ecological modernisation” narrative within climate change posts on the Chinese platform Weibo.

Another potential avenue is to further explore qualitative research on the use of social media platforms within different “protest ecologies” (Segerberg & Bennett, 2011). For example, Twitter hashtags act as important organizational mechanisms for protests, but the demands of gatekeeping in these protest spaces presents challenges for the formation of coherent imaginaries within social movements. Alongside the explicitly normative commitments of social movements, future research could also respond directly to Jasanoff's

(2010) description of human-scale imaginations of climate being situated in engagements with nature, by developing the work discussed above on Twitter users as remote sensors. Such research would need to go beyond simple correlations of temperature anomalies with quantity of social media posts. Instead, it could use such posts as a way into more longitudinal, small-scale analysis of social media users' imagination of climate, utilizing qualitative analysis of post content and meaning-making through interactions.

6 CONCLUSION

This article offers the first comprehensive review of the academic literature on social media communication on climate change. Our approach has been both systematic, using a wide range of search protocols to query both the Scopus and Google Scholar databases, and critical, applying insights from the social media literature. In the article we provide three key findings. First, that the literature has a substantial bias toward Twitter: 26 out of 35 articles draw their data solely from Twitter, a platform ranked sixth globally for active users in 2017. This is likely to be due to the openness of Twitter's API to researchers, in comparison with most other platforms; that is, researchers are seeking data where it is most easily available. Second, there are three main approaches taken by researchers to studying social media platforms: through publics, through themes, and through professional communication. Third, that the literature highlights certain empirical findings including: the dominance of mainstream information sources, the prevalence of “settled science” as a means of framing climate change, the presence of polarization and echo chambers within climate change debates, and the relationship between social media posts and local experiences of temperature anomalies.

These findings draw attention to a number of significant gaps in the research literature, which should be urgently addressed if the huge potential of social media as a source of climate change communication knowledge is to be fulfilled. In terms of research approaches, future work should embrace smaller scale studies enabling more detailed insights than big data approaches, non-textual approaches which cover the full range of media visible within social media platforms (e.g., images, GIFs, and videos), and cross-platform studies which investigate the relationships and dynamics operating between different platforms. In terms of research subjects, we identify one fruitful concept from science and technology studies (STS): how social media platforms facilitate or hinder the construction and emergence of new imaginations of climate change within and across diverse local communities.

Social media platforms are integral to a rapidly changing global communication environment. Such platforms shape and organize communication, so are essential sites of, and objects for, social research on climate change. However, these platforms also shape and organize research, providing hugely variable volumes of data depending on the business

models, social pressures and whims of a small number of global media companies such as Facebook, Google, and Twitter. Whatever future paths climate change social media researchers take, it is imperative that they are aware of these roles and collect the data necessary to answer the key questions in the field, such as those connected to climate imaginaries, rather than being unduly attracted toward those platforms where data is easiest to access. The literature to date, while insightful, is hugely biased toward Twitter studies. Researching other social media platforms may prove more resource-intensive and less amenable to “big data” studies, particularly as access to platforms such as Facebook and Instagram becomes more restricted (Bruns, 2018; Gangneux & Docherty, 2018; Rieder, 2015, 2016). However, it is essential that the academic community overcomes such hurdles if it is to provide a more balanced and insightful knowledge base about climate change communication on social media.

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