Title: Public communication by climate scientists: what, with whom and why?

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Abstract

Public communication of science has increasingly been recognized as a responsibility of scientists (Leshner, 2003). Climate scientists are often reminded of their responsibility to participate in the public climate debate and to engage the public in meaningful conversations that contribute to policy-making (Fischhoff, 2013). However, our understanding about climate scientists' interactions with the public, and the factors that drive or inhibit them, is at best limited. In a new study, we show that it is the most published and not necessarily the most senior, that often talk in public, and it is primarily intrinsic motivation (as opposed to extrinsic reward), that drive them to engage in public communication. Political orientations, academic productivity, and awareness of controversy the topic raises in the public domain were also important determinants of a climate's scientist public activity. Future research should explore what is required to protect the intrinsic motivation of scientists.

Keywords: science communication, surveys of scientists, public engagement, climate change

1 Introduction

Climate change communication and its effects on society have been examined through analysis of media frames and coverage (Schäfer & Schlichting, 2014; Boykoff, 2007), policy discourses (McCright & Dunlap, 2011), framing of debates (Nisbet, 2009; Moser, 2010), and most of all, in analysis of public understanding, attitudes, values and behaviour towards the climate problem (Pidgeon, 2012; *The Politics of Climate*, 2016; Kahan et al., 2012). What has received little attention in climate communication is the supply side: how climate scientists are engaging with the public. Highly regarded and trusted on the causes of climate change (Kahan *et al.*, 2012), and major actors in the climate debate, this is somehow surprising. To date, the existing literature is scarce and has mostly focused on case-study analyses of specific forms of engagement including climate scientists' uses of traditional news media (Ivanova *et al.*, 2013; Post, 2016, Tosse, 2013) and social media networks (Schäfer, 2012), stakeholder engagement (Anderegg *et al.*, 2010; Prokopy *et al.*, 2015; Wilke and Morton, 2015), and to a lesser extent, behaviours of climate scientists or what mobilizes them to go public (Sharman and Howarth, 2017, Hosse, 2013). These studies point to a close relationship between climate scientists and the media, despite only a small number interacting with journalists frequently or contributing to policy (Lehmkuhl, 2012), often high-ranking scientists with a stronger focus on climate research and social scientists (Ivanova et al. 2013, Bray & von Storch, 2007, 2010). When it comes to content, climate scientists choose not to communicate uncertainties about climate change to journalists, distancing themselves from environmentalists and other interest groups (Post, 2016), and political purposes (Tosse, 2013). Despite the contribution of these studies to our understanding of climate scientists' media interactions, a survey based analysis of the broader public communication activity and motivations of climate scientists has not been conducted and would allow for an understanding of the degree of mobilisation for public engagement of this community and factors that drive that mobilisation, and inform future discussions on climate public engagement. This would then inform other analyses that focus on the audience side – what various publics take away from interactions with climate scientists.

2 Background

Previous studies of scientists have pointed to public communication being an elitist activity amongst the most senior (Dunwoody and Scott, 1982; Dunwoody and Ryan, 1985; Jensen, 2011) academically productive (Dunwoody and Scott, 1982; Bentley and Kyvik, 2011), male scientists (Crettaz von Roten, 2011). Some limited studies suggest that scientists used as sources by reporters tend to be those in positions of authority (deans, directors, department heads) rather than necessarily those with the best expertise for the topic (Shepherd, 1981). To explain why communication is performed actively only by a minority, scientists blame lack of communication skills, time, institutional support, and recognition to greater involvement (Royal Society, 2006; Peters *et al.*, 2008; Dunwoody, Brossard and Dudo, 2009); they say, however, that they would be willing to engage more with the public if there were rewards and recognition for their work (Royal Society, 2006), with many recognised scientific institutions having created prizes and grants to motivate more scientists to communicate (e.g. RS, AAAS, RCUK). Despite the contribution to understanding the communication practice of the individual scientist, the empirical evidence remains inconclusive and sometimes contradictory. Few studies have relied on a theoretical framework that allows to understand what factors are most important in scientists' public communication. And, those that do, have considered scientists' intentions as measured by a scientist willingness to participate rather than his/her actual behaviour (Poliakoff and Webb, 2007; Besley, Oh and Nisbet, 2012). But, intentions to participate do not explain why scientists communicate, and might not be reflected into behaviour. For example, enjoyment has been identified among medical scientists' as an important motivation for their interactions with the media (Peters *et al.*, 2008), but enjoyment does not seem to feature as an important predictor of nanoscientists' intentions to engage in public communication (Dudo *et al.*, 2014), a claim which might be based on attitudes, descriptive norms and perceived behavioural control (Poliakoff and Webb, 2007). This may be an indicator that it requires more than intentions for a scientist to engage with the public, it may also be a result of disciplinary cultures. General studies of scientists point to different disciplinary cultures in science communication with fields less likely to engage with the public such as the natural sciences and engineering (e.g. (Kreimer, Levin and Jensen, 2011, Johnson, Ecklund and Lincoln, 2014) and engaging in different formats of engagement. Far less in known about the factors that drive these differences across scientific disciplines within broad scientific areas. Recent work by Entradas and Bauer (2017) has pointed to significant differences in the engagement practice of natural scientists, with some disciplines very much engaged with the public and others less. Much then remains to be understood about the influence of each factor on a specific community's behaviour, and most importantly, how internal and external factors behave in specific communities when considered together. Better understanding of these factors might suggest analyses that focus on audience reception of communication by and with scientists. Here we consider scientists' reported participation/non-participation in climate science communication and challenge some of the previous findings.

Our approach to communication uses a framework model derived from Lewin's long-standing generic model of behaviour that takes into account the total situation (Lewin, 1936, 1951). Similarly, we consider *communication activity (C)* a function of the person-in- context. On the person side (P) this includes his/her psychological orientations towards public communication, and on the context side, we refer to the social situatedness (S) or positioning of the communicator in his/her social space. This can be conveniently expressed with the formula *communication activity* $C = f(P, S)$[i]. Here we are saying that scientists' communication activity (C) is a function of personal factors (P), and situational factors (S) combined, and this combination might be a characteristic of a specific scientific community such as the climate scientists. By personal factors (P), we mean perceptions, opinions, beliefs and motives that indicate commitment to public communication; by situational factors (S) we refer to indicators of the person's positioning in his/her social space (environment) including gender, hierarchical position on the job, and academic productivity, which characterize the context of communication activity. This framework comprises factors often correlated with scientists' public communication: (P) are the subjectively expressed indicators, while (S) brings together the more objectified indicators. Other objective (S) factors could include features of the organisational context such as help from PR officers and funding (Entradas and Bauer, 2018, Marcinkowski et al., 2013). We included motives and perceptions because they are covariates of actual behaviour (Deci and Ryan, 1985), and they are particularly relevant in the context of controversy (Peters *et al.*, 2008). This framework is then helpful to think about the influence of these two sets of conditions in scientists' communication behaviour and can provide insights into the choices of climate scientists to communicate, which might be useful to further the involvement of scientists' in public communication.

3 Methods

We studied a sample of climate scientists, members of the American Geophysical Union (AGU), with a twofold goal: to characterize what and with whom climate scientists communicate, and to examine what factors explain the variance of that participation.

3.1 Procedure and sample

An online survey was conducted between March and end April 2016 with AGU active researchers in climate research (N=3679). Respondents were selected according to scientific area focusing on those whose research is connected to climate change. The list comprised members from the AGU Ocean Sciences only, whose research focused on studying the role of ocean in the climate system. After data cleaning, the total sample consisted of 425 respondents, for a response rate of 12%. The majority of the respondents were male (67%, N=256) and 33% were female (N=128); 63% (N=252) were in senior positions and 37% (N=148) were junior; the average number of publications in the previous five years was 10.5 (N=394, sd=10.6). Most were employed in Public Research Universities (45%, n=190), Government Agencies (22%, n=93) and private Research Universities (9%, n=40); and a minority worked for NGOs or non-profit organizations (8%, n= 32), private companies (7%, n=29) or other university/college (10%, n=40). The average number of researchers per host institution is 1926 (n=417, SD=4130.8) and 83 per research institution (n=400, SD=393.5).

3.2 Measures

Dependent variable

Participation was given by the reported participation/non-participation in public engagement activities, coded (1) for participation and (0) for non-participation. We asked scientists whether they had participated in public engagement activities in the previous year. We then asked communicators for counts regarding their participation in various types of public events, news media channels and social media, in the previous year; and about the frequency of contact of various types of audiences (See SI for full description). To address our second goal, we measured explanatory factors identified in previous studies including socio-demographics, perceptions and motivations, and others thought could be particularly important to this specific community such as perceptions on controversy as described below.

Independent variables

Awareness of controversy & political orientations

Because it is still an open question whether public controversy over contested areas encourages or discourages scientists to get involved in public communication, we measured scientists' awareness of the level of controversy their topic raises in the public domain. Respondents were asked to agree/disagree with the item 'My research is controversial in the public domain' on a 5-point scale ranging from 1 (strongly disagree) to 5 (strongly agree). Of the respondents, most agreed (47% (n=197) with the statement and 29% disagreed (n=121) (see TabS1, SI). *Controversy* indicates the degree to which respondents believe public is aware of controversy and is used as a continuous variable.

We also measured scientists' political orientation. Nisbet and Markowitz (2015) show no effect of political ideology on public engagement among AAAS scientists across disciplines (but this may be a result of the small *n* as only 6% indicated their principal field geosciences. There is general scientific consensus on human causation of climate change (Alley et al., 2007; Farnsworth and Lichter, 2012; Bray and von Storch, 2016) – for instance, Bray and von Storch (2016) in an international survey of climate scientists found that 87% are to some extent convinced that climate change is, or will be, the result of anthropogenic cause. Yet, conservative political views have been found to associate with stronger beliefs that climate change is not happening (McCright and Dunlap, 2011a), which could impact on scientists' public communication. So we wanted to examine climate scientists' political orientations and whether they were a driver of communication. Respondents were asked to indicate their political orientation on 5 options ranging from very conservative to very progressive. Most respondents (74%, n=270) hold progressive views, 24% moderate, and 3% conservative (see TabS1, SI for respondents' characteristics). The variable was recoded into a dummy with (0) for non-progressive and (1) for progressive.

Motives

Motives have been used without a consistent approach in previous studies. We chose to use a well-developed approach, distinguishing between *internal* and *external motivations* (Deci and Ryan, 1985). Intrinsic motivation refers to performing an activity simply because it is interesting, brings enjoyment and is satisfying, as opposed to extrinsic motivation, which refers to doing an activity because it leads to an external outcome (e.g. fulfilment of role, public support). Moreover, we differentiate two extrinsic motives: 'rewards' such as awards and prizes which can be expected from participating in engagement activities (Royal Society, 2006a), and 'role', i.e. activities that arise from scientists' understanding of their role in public communication as academic researchers (Mead and Morris, 1967; Dudo and Besley, 2016). Construct *motivations* were measured with 12 items, which were accessed using 5-point Likert-scales, ranging from 1 (strongly disagree) to 5 (strongly agree) (see Tab3, SI, for respondents' responses to motives items).

Exploratory factorial analysis (EFA) resulted in a reliable scale for the construct 'motive' (Cronbach's α=0.78) with items loading appropriately in three factors. The internal consistency of this structure was further confirmed with confirmatory factorial analysis (CFA), (χ^2 =104.39, df=51.00, χ^2/df = 2.05, CFI=099, RMSEA=0.05) (see TabS4a and S4b, and Figure S1). The factors were labelled '*intrinsic motivation'*, degree to which respondents enjoy public communication; *extrinsic motivation 'role'*, degree to which respondents believe they have an obligation for public communication; and *'extrinsic motivation reward'*, degree to which respondents are seeking prizes or recognition. Indices for high and low motivations were constructed using CFA scores (median split): 'intrinsic motivation' 'extrinsic motivation role' and extrinsic motivation reward were coded (0) for *low* (below the median) and (1) *high* (above the median) level of motivation.

Public perceptions

Questionnaire measures of the construct perceptions of the public included 8 items, positively and negatively worded, which respondents were asked to agree or disagree in a 5-point Likert scale (strongly disagree=1 to strongly agree=5) (see TabS5, SI for responses for these items and percentage of the respondents agreeing with each statement). These items were informed by studies in the PUS literature that point to the importance of views on the public to scientists' communication, in particular views about the public participation in policy making (e.g. Entradas, 2016), which we thought could be particularly relevant to a community involved in controversy.

Principal Components Analysis (PCA) and CFA (Confirmatory Factorial Analysis) loaded in two factors showing a strong fit to the data (KMO=0.72; χ^2= 18,23, df=13, χ^2/df= 1.40, CFI=1.00; RMSEA=0.03) (see Tabs 5, SI). Factors were labelled *'deficit'* (degree to which respondents believe public are interested and know about science), and *'participative'*, degree to which respondents believe public should participate in climate science policy making. Indices for the two factors were constructed using CFA scores (median split) and recoded into negative (0) and positive (1) images of the public according to agreement/disagreement to the public level of interest/knowledge in science and their public for decision-making.

Respondents were also asked contextual information such as *gender*, *seniority positioning in the organisational hierarchy,* and *academic productivity* as given by the number of peer-reviewed publications produced over the previous 5 years; academic productivity was recoded into a binary using median split '>= 8 publications' '< 8 publications', and seniority was recoded into a binary 'junior' and 'senior' (see TabS1, SI).

3.3 Analysis

We considered social situatedness (S) with gender, seniority and academic productivity, and personal orientation (P) with the perceptions of the public, motives to communicate and political orientations of scientists (conservative vs progressive). We investigated the relative influence of (P) and (S) variables on scientists' participation in four models using logistic regression. We are modelling the likelihood of a scientist being a communicator versus non-communicator using the constructs described above and dependent variable ‘participation’.

Models 1, 2 and 3 show the independent influence of each set of factors on participation, and Model 4 shows which factors are the most important determinants of participation when both (P) and (S) are considered. All sets of variables explain a significant amount of the variance in the outcome variable, which increases from model to model, reflecting the importance of each set of variables separately, and uncovering the most significant drivers of scientists’ engagement in public communication (Tab1).

Variance Inflation Factor (VIF) was used to test for multicollinearity among predictors. We report Nagelkerke’s R2 and the predictive accuracy indexes of the models. Reference categories for our predictors were as follows: *female* for gender, *senior* for seniority, >= *8 publications/5 years* for academic productivity, *progressive* for political orientation, *positive* image for variables *deficit* and *participation* and *high* for intrinsic and extrinsic motivations by ‘role’ and ‘rewards’.

4 Results

4.1 Public communication activity of climate scientists

Our data show that climate scientists have an intense interaction with the public: 73% of all respondents said they had engaged in public communication initiatives in the past 12 months (N=308); the average number of activities per active researcher per year was 14 activities (the median is 9 activities). This represents an average of 9 public events and 5 media contacts per active climate scientist. Comparatively, participation in public events is more common than media interactions. Yet, only 33% of climate scientists can be considered ‘highly active’ (i.e. engaging above the average), showing a diverse mobilisation of climate scientists with some performing very much above average and others very much below. Notwithstanding, these numbers are high when compared with studies of natural scientists: for example, Jensen (2011) found 0.8 activities per environmental French scientist (Jensen, 2011), and Entradas and Bauer (2017) found 0.6 activities per Portuguese natural scientist (Entradas and Bauer, 2017); while studies across all scientific areas show a 10% of ‘highly active’ communicators (Dunwoody and Scott, 1982; Royal Society, 2006). Methodological differences, in particular the broad research areas considered, could in part explain this gap in the results. Yet, the public communication activity found among AGU climate scientists is similar to that found amongst other communities of climate scientists. In 2012, 67% of German climate scientists reported at least one contact with news media (of these, 12% reported more than six contacts), 47% with a policy actor, and 54% had contacted with a non-governmental organisation (Ivanova et al., 2013). Importantly, these studies including ours presented here, suggest a community of highly engaged communicators amongst climate scientist. The high public communication activity found amongst climate scientists and astronomers (Entradas and Bauer, 2018), put into perspective general claims that natural scientists communicate less than social scientists. This highlights the need to study specific communities to better understand their unique characteristics.

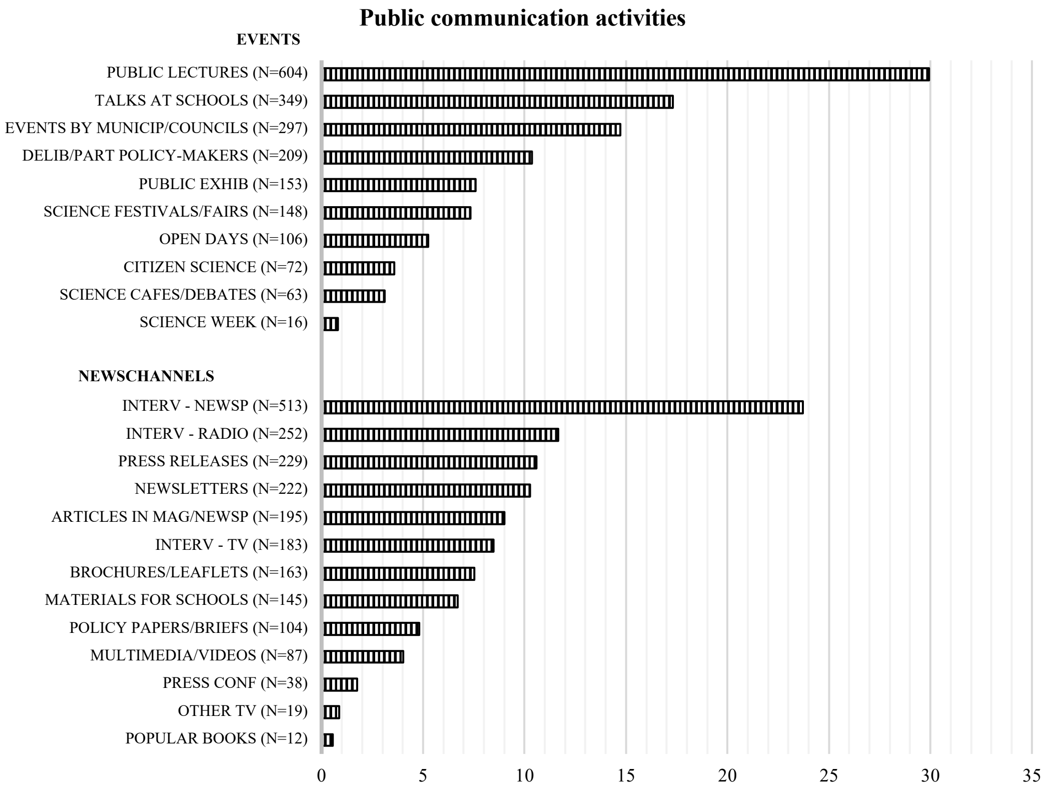

Fig1a

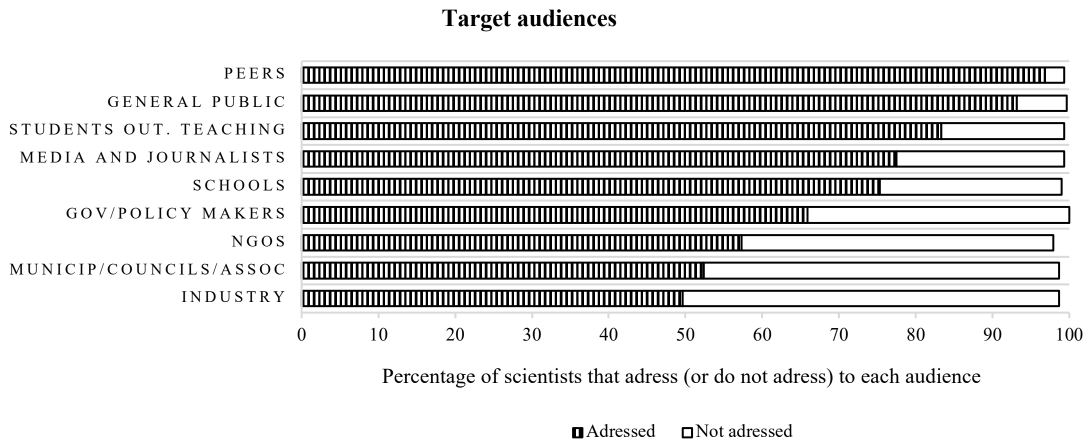

Fig1b

Fig 1. Fig 1a shows the type and intensity of public engagement activity – public events and news media channels, as reported by scientists. We present the total counts for each activity (N= in each row label), and within each group of activities. The bars in the chart show the percentage which that activity represents of the total, taking all activities in that group as the basis for 100%. For example, amongst all types of events, 30% of the events in which climate scientists engage are public lectures. A total of 4179 public communication activities were reported. Fig1b represents the frequency of scientists' contact (or no contact) with different audiences. Data are self-reported estimates and should be interpreted carefully.

Fig1a shows that the most popular public events in which climate scientists participated were public lectures and talks at schools followed by workshops with local government/councils and participatory events in policy making[ii]. While high levels of involvement in two-way policy-oriented events are have not commonly been found amongst natural scientists (Entradas and Bauer, 2017), the high level of involvement of climate scientists in such events is perhaps not surprising given the high politicization of climate change (Alley *et al.*, 2007), which often involve scientists. Climate scientists' level of contact with the media is also high when compared with other (even controversial) disciplines. For example, 44% of the surveyed climate scientists reported more than two contacts with news media channels[iii], compared to 33% of German medical researchers (stem cells and epidemiologists) who reported more than two contacts a year (Peters *et al.*, 2008), a further indicator of the medialization of climate science (Boykoff, 2011; Ivanova *et al.*, 2013). Although methodological aspects do not allow for direct comparison, the intense media activity of climate scientists is found in other countries as well, suggesting an active community in the climate public discussion, regardless of country. In 2012, 41% of the German climate scientists contacted with a newspaper and 33% with the radio. Among our respondents, 47% contacted at least once with a newspaper and 32.8% with a radio. This may be explained by the internationalization of climate change, a social, political and scientific issue that impacts on the lives of every citizen. Also, consistent with previous studies (Schäfer, 2012), we found that social media channels are not much in use by climate scientists for public discussion, with the large majority reporting they never used them; within that smaller set, Twitter was amongst the most used, Facebook and blogs were used a few times a year (Fig2). Contrary to traditional communication means, social media networks are more in use by less academically productive scientists (e.g. 9% of highly ranked respondents reported using Twitter weekly or daily versus 20% of lower ranked scientists) ($p<0.01$). Despite the big promises of social media to engage the public in conversations about climate science, these communication means do not seem to have yet been adopted by scientists – if they ever will. Within the whole picture, traditional means are preferred. While we cannot fully explain the reduced use of social media by climate scientists, one possible explanation is climate scientists' fear that their results are misinterpreted by the public or journalists or exploited by interest groups (Post, 2009), which inhibit them to use these fast propagators of fake news (Vosoughi, 2018).

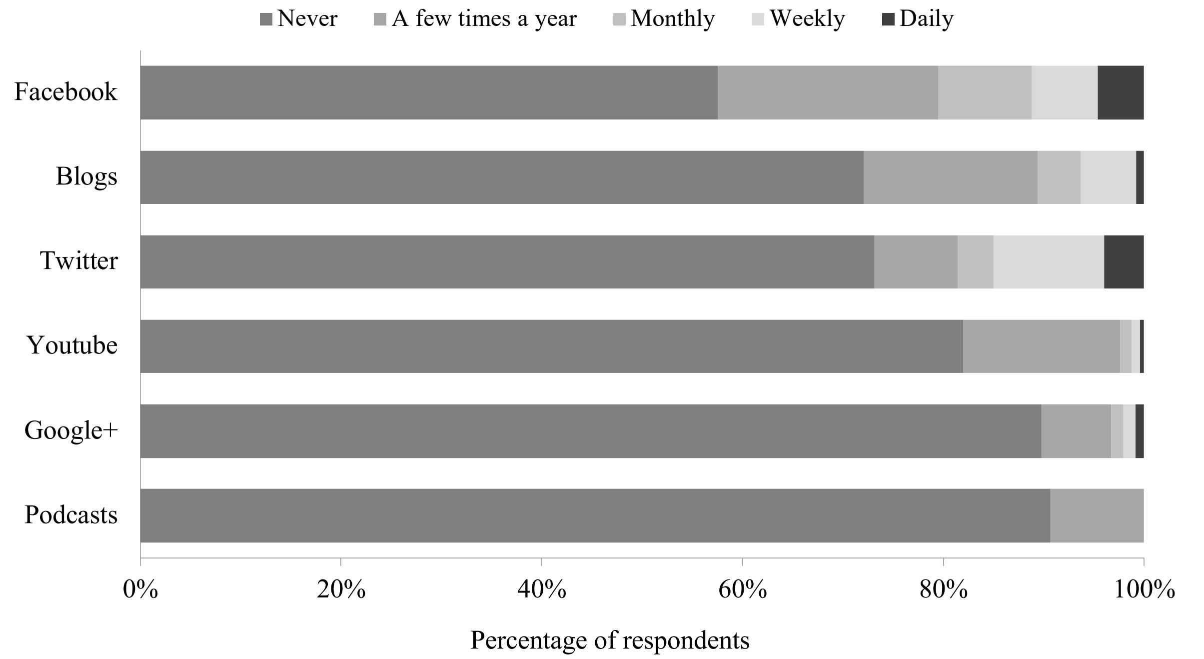

Fig.2 Frequency of use of social media networks by climate scientists. Percentage of respondents who reported using each of these means are shown

4.2 Understanding drivers of scientists' climate engagement

Corroborating previous surveys on scientists across disciplines (Dunwoody and Ryan, 1985; Jensen, 2011) we show that, when (S) factors are considered alone (Model 1), also in climate science communication it is the more senior and academically productive scientists that communicate more. Ivanova et al. (2013) found media interactions more common amongst high-ranking climate scientists. The fact that the most senior and reputable scientists are often those sitting on committees and advisory policy panels, and requested for media interviews (Peters *et al.*, 2008; Crettaz von Roten, 2011) could in part explain these effects. But these findings are challenged when (S) factors are combined with (P) factors (Model 4): Seniority loses significance and academic productivity remains significant, suggesting that academic productivity is a more important factor than seniority. It is then the most published and not necessarily the most senior climate scientists that often talk in public.

Independent Variables	Model 1 Estimate	SE	Wald	Model 2 Estimate	SE	Wald	Model 3 Estimate	SE	Wald	Model 4 Estimate	SE	Wald
Gender (Female)	-0.265	0.263	1.012							-0.142	0.305	0.216
Seniority (Senior)	-0.643*	0.253	6.452							-0.513	0.301	2.894
Academic product (>=8 /5 year)	-0.594*	0.243	5.974							-0.818**	0.290	7.978
Political Orientation (Progressive)				-0.833***	0.238	12.288				0.829**	0.288	8.277
Perceptions on controversy (not)				0.304**	0.100	9.214				0.319**	0.118	7.28
Deficit (positive)				-0.42	0.232	3.277				-0.740	0.278	0.070
Participation (positive)				-0.65**	0.213	7.904				-0.372	0.274	1.848
Intrinsic Motiv (high)							-1.635***	0.319	26.235	-1.915***	0.385	24.781
Extrinsic Motiv (Role) (high)							-5.68	0.313	3.287	-0.512	0.376	1.852
Extrinsic Motiv (Rewards) (high)							0.494*	0.230	4.623	0.159	0.273	0.341
(Intercept)	1.579	0.303	27.105	0.643	0.407	2.492	1.661	0.230	52.087	2.381***	0.617	14.914
Nagelkerke R^2	0.058			0.169			0.255			0.395		

Note: *p < .05, ** p < .01, *** p < .001. Dependent Variable ‘participation’: ‘Do you undertake any public communication activities for the non-specialist public? For example, do you maintain a website/blog/social media for the public, participate in science cafes, give talks at schools, give public lectures, respond to media inquiries, etc.?

Tab1. Tab1 shows binary logistic regression models representing the predictive power of S and F factors on scientists’ participation in public communication. Reference categories are represented in brackets. By order of magnitude, Model 4 shows that the most important drivers for a scientist to engage with the public are intrinsic motivation, political orientations, academic productivity, and awareness of controversy. Moreover, Model 4, explains 40% of the variance of scientists’ participation in public communication offering a strong fit when compared to previous studies, which have analysed constructs separately.

We also show that views of the public matter (Model 2). Perceptions of a deficit public do not influence participation, perhaps given that an image of an interested, trusting public prevails over a deficit one, but images on the role of the public in contributing to research and policy do. Those thinking that the public should be involved in climate research and policy discussions were 46% more likely to engage in public communication than those holding negative views on public participation; but this is the view of a minority (e.g. only 18% agreed that the public should not be involved in the decisions about their research; see Tab5, SI). And, this relationship loses significance in Model 4.

Motivations both intrinsic and ‘rewards’ were strong predictors of participation (Model 3). Those engaging with the public were those more likely to be highly motivated while also less likely to perceive extrinsic rewards as important. This suggests that rewards, while not important drivers for those already engaging in public communication, may work as a barrier for those who do not engage, particularly for younger, less productive researchers. In fact, rewards lose significance in Model 4. Dunwoody, Brossard and Dudo (2009)'s study with US stem cells researchers and epidemiologists interacting with the media, found no associations between perceptions of extrinsic rewards and intensity of scientists' contact with the media (an activity of the most senior), but rewards were valued by Spanish young researchers attending a science fair (Martín-Sempere, Garzón-García and Rey-Rocha, 2008). 'Role' was not significant. We found no significant differences in the perceptions of 'role' of those who publicly engage and those who do not. This does not mean however that scientists did not see public engagement as part of their role. In fact, only a minority saw 'public engagement as a hobby' (16%). In other words, some scientists despite not participating recognise public engagement as part of a scientist's role.

When both (P) and (S) factors are in the same model (Model 4), intrinsic motivation explains most of the variance in scientists' engagement with the public (Wald=24.8), followed by political orientations (Wald=8.3), academic productivity (Wald=8.0) and views on controversy (Wald=7.3), seniority is not significant (Fig3). That is, it mainly is the self-enjoyment and satisfaction that public communication activities bring that turn scientists to the public. A highly intrinsically motivated scientist is 85% more to engage in public communication. This corroborates findings from previous studies that have found enjoyment to be an important factor (but not the most important) in scientists' interactions with the media (Dunwoody, Brossard and Dudo, 2009). Our study indicates that when it comes to actual participation, it is the satisfaction that scientists feel that matters most while external motivations are not likely to drive scientists to public communication initiatives. This is interesting. Enjoyment has been often identified as an important feature in scientists' public communication, but its explanatory power has been rarely discussed. Comparable data would be needed to conclude on whether these features are specific of this community or are found elsewhere.

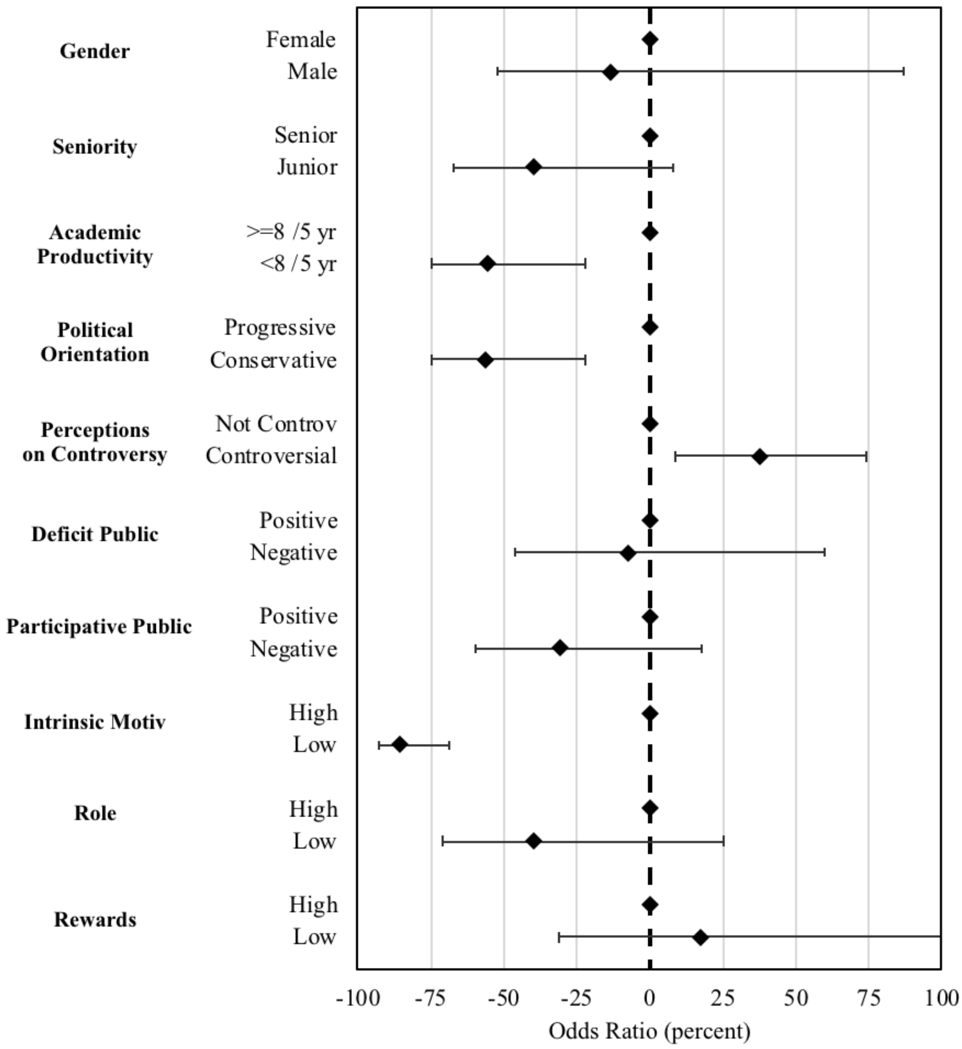

Fig3. Forest plot showing binary logistic regressions for communication activities when both (P) and (S) variables are considered (Model 4). Dependent variable is participation/non-participation. Model include 'communicators' only. Data correspond to odds percentage ratios and 95% CIs. The plot presents the likelihood of being a performer in public communication. Diamonds represent the odds % and the whiskers the CIs. Significant associations are shown when CIs do not overlap with 0. Diamonds on the line are the reference categories.

Also, the awareness of controversy is an important factor. Climate scientists perceiving their topic as controversial in society were 37% more likely to engage with the public. This is expected, as those more aware of the controversy of climate change also have a higher sense of responsibility for communication and may be moved by an aspiration to counteract public disbelief in climate change. Scientists' engagement is also a function of political orientations, with those holding more progressive views also being more likely to engage in public communication (56% more likely). It is possible that those scientists with more progressive political views, perceiving the risks of climate change more seriously (Farnsworth and Lichter, 2012), take responsibility for public communication either as an attempt to correct public misconceptions and convert those more skeptical members of the public, or because they fear that a public that does not believe that climate change is human caused (Weber and Stern, 2011) is less likely to support government commitment to international climate policies. It is interesting to note that most scientists surveyed (57%) agreed they 'should engage with the public to get the attention of policy-makers as policy makers respond more to the public than to scientists' (12% disagreed), while also agreeing that their research 'has implications to policy makers' (87%). This seems to suggest that the public is seen as a means to influence policy. This could however be unique of this community and the United States context, where scientists may face more challenges to communicate climate change to a society where half of the public rejects that climate change is caused by human activity (Roser-Renouf et al., 2016) and a country that has recently withdrawn from the Paris Agreement on Climate Change pointing to a political disbelief in climate change.

5 Discussion and Conclusion

We identified the public communication activity of the AGU surveyed climate scientists and relative contribution of (P) and (S) factors to the variance in their public participation activity. Our findings have implications for the practice of communicating climate change and science communication research more broadly. Firstly, we found that the surveyed climate scientists are active public communicators, with dynamic relations with the public, the media and policy actors, while engaging in both one way and two-way types of public communication approaches, some policy-related. We cannot, however, conclude on the quality of such interactions and whether this involvement leads to better public debates and policies. Partly, this is a limitation of our study, which focused on scientists rather than on audiences. But also, as we show here, public input in climate policy is marginalized by those scientists not perceiving the substantive value of public participation for policy making, drawing a boundary between what is public communication and what is policy; a view that has been suggested to be linked to political authority in policy-making (Entradas, 2016). More should be done to draw climate scientists' attention to the importance of public participation in research and policy, and to reflect on social impacts of their communication, which could be reflected on training directed at climate scientists – this should aim at awareness on the importance of dialogical approaches to engage the public in the climate debate, to communicate uncertainty and risks of climate change to a reluctant public to accept the anthropogenic causes of climate change (Weber and Stern, 2011; Roser-Renouf, 2016; Kahan, 2012) and to value public communication opportunities to engage and pursue the public to act.

Secondly, we show the importance of (P) and (S) to scientists' engagement for this community. Yet, similar to previous studies, we show that personal factors explain only a part of the variance in engagement meaning that other important factors are at stake (Socio-demographics explained 6%; perceptions alone accounted for 17%, and motivations accounted for 26% of the variance). Importantly, our data suggest that while some factors seem to be important drivers amongst scientists from different disciplines, others may be specific to scientific communities as we show here by the importance of political orientations and awareness of controversy for climate scientists. It is important that detailed studies of scientific communities are conducted to better understand and address needs of particular communities. Hitherto, outreach across the sciences has been the main focus of research; over the near future we need to compare the outreach in different scientific communities in greater detail. What is at stake in this mobilisation effort was traditionally the reputation of science, but increasingly it is the reputation of specific communities of science that take precedence; this might entail competition for public goodwill among different sectors of science.

Thirdly, our research disentangles the contribution of intrinsic motivation to participation, over and above the other factors with the public. Nevertheless, one could argue that social desirability bias could artificially suppress the effect of external motivations as a scientist may be more inclined to report an altruistic motivation than one that is driven by prizes. But the fact that enjoyment is a common factor in other studies of scientists seems to leave little reason to believe that this should not be the case. Future research should examine the social contexts and individual differences that support autonomy and satisfaction, and what is required to protect intrinsic motivation, to prevent it being crowded out by extrinsic rewards, which are the least autonomous form of extrinsic motivation (Deci and Ryan, 1985). This has implications for scientific institutions that are to implement more strategic approaches to scientists' public engagement with the building of normative and reward structures, which could crowd out scientists' existing intrinsic motivations for engaging with the public, a shift that could have more cost than benefit.

Limitations

As noted above, an inherent limitation of this study is the focus on scientists – the supply side. Our study does not claim to address the demand side – audience reactions, motivations, behaviours, etc. More directly, another inherent limitation of this study is the risk of non-response bias by those predisposed to engage with the public given that respondents were self-selected. To minimize this, when collecting the data, we explicitly invited 'non-communicators' to participate saying that the study was aimed at both communicators and non-communicators. We cannot however conclude that the relative numbers of communicators to non-communicators represent the ratio in this community as we do not know the distribution in the population. But representative studies with a focus on funded scientists across disciplines and of the climate scientific community in other countries (only 16% of German climate scientists had no contact with public audiences, Ivanova et al., 2013), show that most scientists do something, few are very active. The percentage of non-communicators in our study is similar to these. We have no reason to think that the distribution of activity would be different across our sample. Our response rate is acceptable when compared to response rates of similar online surveys of scientists or surveys of other scholars including economists, lawyers or engineers (Schützenmeister and Bußmann, 2009). With a few exceptions, most previous surveys of scientists' engagement have relied on small, and/or convenient samples, while larger-scale national surveys have usually combined scientists from various disciplines (e.g. Royal Society, 2006, Pew surevys of scientists). Also, our *n* considers only scientists from the same field of research. Similar surveys include Dudo, Kahlor, Abighannam, Lazard, & Liang (2014) which surveyed 240 US nanoscientists (response rate of 25%), Besley, Dudo, & Storksdieck (2015) and Dudo & Besley (2016) based conclusions on a 9% and 8% (respectively) response rate of AAAS members. While not inferential, our findings provide indications on factors that drive climate scientists engagement; and more broadly, communities involved in controversial topics. We believe it is unlikely that the relationships investigated in our sample would become insignificant in a larger sample or with members from different organisations/associations. Overall, we believe the strengths of our sample much outweigh its limitations.

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Author contributions statements

ME designed the study and wrote the paper; MB provided inputs and feedback into the paper and conceptual advice. BL supported data collection in the US and provided feedback into the paper. ME and JM conducted the data analysis and JM compiled the presentation of the data.

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[i] This expression derives from Lewin's (1936 and 1951) original equation $B= f(S)$ where behaviour is a function of the total situation (S), i.e. all potential factors attributable either to the person (P) or the environment (E), expressed as $B= f(P, E)$. In our framework, this becomes a linear combination of two different sets of observed predictor variables.

[ii] Our research cannot conclude to whether these participatory events were attended by members of the public and if so, what the impact on policy of that involvement was.

[iii] Media contact is given by counts of activities involving the media including interviews for newspapers, radio and TV, press releases and articles for magazines and newspapers, by number of active researchers.