

# quest

D1.1:

## Summary report: European Science Communication today

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# EXECUTIVE SUMMARY

QUEST defines, measures and supports quality in science communication. In this research, the project sought to understand what is happening in contemporary European science communication, without necessarily evaluating or assessing these practices. It used interviews, literature reviews, quantitative social media analysis, and ethnography to do this.

‘Science communication’ may be a field of practice or a domain of academic research. As a field of practice, it is frequently framed as a means to bridge a gap between science and wider society. Academic literature on it has been oriented towards distinctions between ‘one-way’ communication, often understood as less effective, and two- or multi-way communication, which may be understood as substantively and/or normatively superior.

Despite commonalities in the academic literature on science communication, there is little evidence that science communication is a coherent research field. The scholarship is constantly shifting as different centres and individuals rise to the fore, and it is fractured along lines such as national context and disciplinary affiliation. Stakeholders represented the field as necessary shifts from an instrumental approach (oriented to changing behaviours) and to embrace a more critical role in assisting interactions between science and society.

The literature on science journalism offers a number of roles for science journalists. Such journalism may be ‘routine’, and rather uncritically report on and cheerlead for science and scientific discoveries, or ‘mediatized’, where a more critical stance is taken. Science journalists have established their own professional set of routines and standards, though there is evidence that journalistic practices are shifting.

Science journalists themselves similarly disagreed about the role of the science journalist. Several argued that science journalists’ role was not to confine their reporting to simply translating complex science or giving a platform to new discoveries. Rather they should go beyond translation or cheerleading to investigate science policy and funding and challenge ‘bad science’. Funding - in the context of shifting media landscapes - was a central concern. Other challenges included the need for scientific literacy, trust (with sources and audiences), and the concept of fake news.

The literature on science on social media is limited. Most studies are either limited to one topic, short time frames, a single social media platform or use small datasets. QUEST research finds that, since 2010, science communication has increased on Facebook and YouTube. Some countries display a preference to publish content on a given social media platform: Italy and Facebook; the UK and

Twitter; France and Germany and YouTube. Twitter displays a greater variety of science content than Facebook and YouTube, and YouTube display considerably less variety than Facebook and Twitter. When they have an account on a specific platform, science journalists, scientists or other experts, and representatives of industry receive high engagement from their audiences. Indeed, scientists and experts have a higher median engagement volume than science journalists on Twitter (as measured through retweets).

In the context of science in museums, both academic literature and museums practice suggests that there is an urgent need to make science museums more socially inclusive, and for them to engage a wider range of audiences. Inquiry-based approaches have risen to the fore in contemporary museums practice. These empower audiences to follow their own curiosity and to be active in the museum's experience. Museum stakeholders also emphasise the value of dialogic approaches within museums. While scientific accuracy is important as a baseline for quality, an exchange of ideas between researchers and public audiences is viewed as most productive for inspiring and empowering visitors.

These findings suggest a number of cross-cutting themes and challenges. First, critical and dialogic approaches to science communication are generally understood as especially important and as being of higher quality. Second, format matters, in that there are central differences between science communication practice in different contexts. Third, science communication is in transition. The landscape of European science communication is shifting due to, for instance, changes in print and legacy media more generally and the rise of digital and social media.

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# SECTION 1: INTRODUCTION

This report summarises work carried out within Work Package 1 of the QUEST project. It draws together findings from four tasks, each of which focused on a different aspect of the contemporary European landscape of science communication: research, science journalism, social media, and museums.

As a whole, [QUEST](#) defines, measures and supports quality in science communication. The project will, at a later stage, develop tools and guidelines for improving effectiveness in the dialogue between science and wider publics. This Work Package, however, serves a descriptive rather than a normative function. The tasks that comprise it have sought to understand *what is happening* in contemporary European science communication, without necessarily evaluating or assessing these practices.

This report thus offers a series of snapshots into science communication as it is currently practised, studied and discussed across Europe. These snapshots are not comprehensive, but they do provide important data on the key issues that are at stake and the central challenges facing (different aspects of) science communication.

Task 1.1 focused on science communication research, asking what the current status of academic thinking on science communication in Europe is through both literature reviews and interviews with key scholars and educators. Section 2 describes key findings from this work, making an argument that science communication scholarship is a fragmented field.

Section 3 draws on Task 1.2, which sought to examine current practice and emerging challenges in science journalism. It also involved literature surveys and a set of interviews, this time with individuals working in science journalism across Europe. Section 3 reveals a domain in flux, due to changes such as the fall of traditional print media and attendant concerns about funding.

Task 1.3 explored the landscape of science on social media, using big data analytics from Facebook, YouTube, and Twitter. Section 4 provides an overview of this analysis, showing how science on social media has grown in line with increased use of platforms such as Facebook and Twitter, the different ways that such platforms are used, and some of the differences in social media use in different European countries.

Finally, Task 1.4 focused on science in museums. It involved interviews with museum stakeholders across Europe and a case study of one science museum (Science Gallery Dublin). Section 5 summarises outputs from this work, depicting a domain in which science museums are increasingly being forced to confront their limited and highly non-diverse audiences.

As a whole, QUEST also has a focus on three case study topic areas: vaccines, artificial intelligence (AI), and climate change. These case studies formed part of the work in Tasks 1.2 and 1.3, and are discussed in sections 3 and 4.

Section 6 closes the report with a brief reiteration of the key findings across all of the sections, and a discussion of cross-cutting themes and implications.

To aid the reader, key findings are summarised in boxes throughout the text.

# SECTION 2: CONTEMPORARY SCIENCE COMMUNICATION SCHOLARSHIP IN EUROPE: A FRACTURED FIELD

## 2.1 INTRODUCTION AND METHODS

This section of the report provides an overview of contemporary scholarship into science communication across Europe, and is based on two activities. First, a literature review of science communication research, with the aim of understanding key approaches, the limits of current knowledge, and the sites this scholarship (tends to) emerge from. Given that this is a significant and growing field (introductory overviews can be found in, e.g., Bucchi & Trench 2014; Davies & Horst 2016; NAS 2016; Trench 2008; Wilkinson & Weitkamp 2016), in this report the literature reviewed focuses on how science communication is defined and delimited within academic literature, including how the purposes of public communication are described. Second, 16 semi-structured interviews carried out with science communication scholars across Europe.<sup>1</sup> Interviewees were identified from the literature search, from suggestions by QUEST partners, and through snowball sampling (Cresswell 2002). The interviews involved discussion of interviewees' views about contemporary science communication, key concepts, knowledge gaps, and the landscape of science communication scholarship across Europe.

## 2.2 DEFINITIONS

The challenge of science communication, as concisely presented by Newman (2019), relates to a:

lack of connectivity between scientists and society [such that] scientists must develop closer ties to different publics and engage in bidirectional communication. This type of communication reflects the need for science and scientists to integrate the many different needs and values that science meets for society (Newman 2019, 1)

Dealing with this challenge - that is, a gap between science and the wider public (see also Burns et al 2003) - requires clarity in the analysis, content, and practice of science communication.

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<sup>1</sup> The interview topic guide is available in the [QUEST data repository](#).

On the theoretical level, Guenther and Joubert (2017) offer a birds-eye view, presenting a research perspective (cf. Gascoigne et al 2010) where science communication is a:

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dynamic, interdisciplinary field of research that draws from a wide range of disciplines and encompasses a wide spectrum of scientific approaches ... It employs tools and techniques from social and behavioural sciences, as well as from humanities; while scholars in the field are typically trained in social science disciplines such as sociology, communication studies, media studies, or in related fields of humanities such as philosophy or rhetoric (Guenther and Joubert 2017, 1)

If we instead consider the practice of science communication, then Davies and Horst’s (2016) definition of science communication as any “organised actions aiming to communicate scientific knowledge, methodology, processes or practices in settings where non-scientists are a recognised part of the audience” (Davies and Horst 2016, 5) is useful. The definition is broad and can be applied to a wide range of settings, including mass media presentations of science; science in museums; festivals and events; or public lectures and debates (ibid, 3). A further close-up of the practice of science communication by Salmon et al (2017) proposes that the term ‘outreach’ should be used instead of the more common term public engagement with science (PES). According to Salmon and Hoop (2018), outreach has the advantage of including a wide array of public engagement activities that a single scientist might become involved in, including:

both one-way “communication” and two-way dialogue, or “engagement” activities, between scientists and different publics. Adoption of the term “engagement” would assume that the activities include dialogical interaction, where this may not be the case (Salmon et al. 2017: 54)

A definition of science communication is therefore required that can encompass the broad number of fields working with science communication, and in seeking to capture the diverse forms of science communication practice not lose sight of the continuing tension between the deficit model and participation, and the wide variety of settings and formats where science communication takes place. According to Bucchi (2008) this means that “[c]ommunication should not be reified as a circumscribed, static event, nor as a prerogative that can be switched on and off at will. Rather, it should be viewed as a *process* that fluidly assumes different contingent configurations” (Bucchi 2008, 72; emphasis added). Furthermore, “it is not simply a technical tool functioning within a certain ideology of science and its role in economic development and social progress, but has to be recognised as one of the key dynamics at the core of those co-evolutionary processes” (ibid, 73). As such science

communication becomes a tool for knowledge and citizenship, expertise, and democracy (Longnecker 2016).

The faultline through which contemporary science communication has tended to define itself, then, is the contrast between ‘deficit’ (one-way, elitist, ‘fact’-oriented) and ‘dialogue’ (two-way or interactive, participatory, reflective upon technoscience’s broader implications). The various conceptual models that have been developed for science communication tend to confirm this: even where they include three or even four ‘types’ of communication, the one-way/dialogue contrast is central. Maja Horst (2008) distinguishes between *diffusion* (where the emphasis is on the public listening to science), *deliberation* (the emphasis on science listening to the public) and *negotiation* (multi-way, interactive communication) models of science communication. Brian Trench (2008), in a meta-analysis of science communication models, similarly identifies three key formats in which knowledge is understood as primarily travelling to the public; to science; or is constructed in negotiation between them: deficit (or dissemination); dialogue; and participation (or conversation). Palmer and Schibeci (2014) develop a four part typology which also classifies communication based on the primary direction of knowledge exchange but which adds a fourth category, *professional science communication*, which represents intra-scientific communication (such as that which takes place at conferences or in journal articles). These accounts (which draw on other, similar models of the communication process; see Brossard & Lewenstein 2009; Bucchi & Neresini 2007; Kurath & Gisler 2009; Rowe & Frewer 2005) thus classify science communication according to how knowledge, whether that is scientific or lay, is understood as travelling or being constructed.

In sum, this brief survey of literature that has sought to define or model science communication leaves us with a number of central points. ‘Science communication’ may be a field of practice or a domain of academic research. As a field of practice, it is frequently framed as a means to bridge a gap between science and wider society (with these entities being understood as clearly distinct; Michael 2002). Scholarship has been oriented towards distinctions between ‘one way’ communication, often understood as less effective, and two- or multi-way communication, which may be understood as substantively and/or normatively superior (Fiorino 1990).

## 2.3 THE LANDSCAPE OF EUROPEAN SCIENCE COMMUNICATION RESEARCH

This section describes key themes from interviews with key European scholars and educators in science communication, in order to sketch out (their descriptions of) the landscape of science communication research.

### 2.3.1: “People come and go; they grow up and they grow on”: The European knowledge base

In contrast to accounts in the literature, there was little consensus about the overall landscape of science communication scholarship across Europe within stakeholder interviews. Those who had worked in the field for some time noted that it shifted over time: research in particular sites is generally dependent on just one or two individuals, so if they retire or move then that line of work will close. A few sites were mentioned repeatedly by interviewees. The UK and Ireland are framed as having particularly influential research (and teaching)

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programmes in science communication, either via significant individuals or schools ([Brian Trench](#) in Ireland, the [Lancaster school](#) in the UK) or from having what one interviewee described as “continuity of serious intent around science communication” in the shape of an unusual degree of policy attention and funding over several decades. [SISSA](#) (the International School for Advanced Studies) in Trieste, Italy (which hosts JCOM, the open access Journal of Science Communication); [Rhine-Waal University of Applied Sciences](#) in Kleve, Germany; [Imperial College London](#) in the UK; and the [University of Pompeu Fabra](#) in Barcelona, Spain were all described as having particularly long or recently significant histories in science communication, though interviewees also made it clear that there were many other programmes, individuals, or research centres within their local contexts which might not be so well known internationally.

### 2.3.2: A fractured field: Key themes in interviewees’ accounts of the research landscape

The top line from analysis of interviewees’ descriptions of science communication scholarship is, perhaps frustratingly, that there are no clear themes. Participants’ accounts of the research landscape, of influential concepts or bodies of scholarship, and of key challenges or research problems were frequently entirely different from each other, and at times diametrically opposed (one – non-European – example being the science of science communication initiative<sup>2</sup> in the US, which was mentioned either in approving terms, or as being particularly banal and uninteresting, by different interviewees). This diversity is, however, an important finding in itself. European science communication scholarship is not an established discipline working in a widely shared paradigm, but is fragmented along a number of lines. We briefly chart these fractures below.

<sup>2</sup> Featured most prominently in a colloquia series that has resulted in a number of publications: see <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6475368/>.

European science communication scholarship is not an established discipline working in a widely shared paradigm, but is fragmented along a number of lines.

First, many interviewees noted that there are significant gaps between science communication research and practice (something that has been suggested before; see Miller 2008; Salmon & Roop 2019). “How is it”, wondered one interviewee succinctly, “that those who are doing science communication aren't reading the articles, and those who are writing the articles aren't doing any science communication?” Or, similarly:

...there are science communication researchers who are studying science communication and then there are science communicators and they do not communicate with each other. The new methods of science communication that are developed or that are improved or something do not reach the communicators because there is also a communication gap.<sup>3</sup>

While interviewees had different explanations for this ‘communication gap’, the implications were that a growing knowledge base in evaluation of and innovation in science communication from researchers often did not reach practitioners, and that the majority of practice – even that funded through large scale government initiatives – was not evaluated or assessed.

Second, it was clear that national context and region were important in structuring communities of both science communication research and practice. “Each country has its particularity”, said one interviewee. National differences might be due to specific cultures that had grown up around thinking about and doing science communication but, more concretely, were also focused on language groups. French, German, English, and Spanish-speaking countries (in particular) all have long histories of carrying out, teaching, and researching science communication, but these histories have been articulated in quite different ways and discussion of them has tended to be done within that language. For instance, one interviewee said that:

France I have to say I don't know that well. My impression is that the connection between the French-speaking world and certainly the German-speaking world, probably also the English-speaking world, is not that strong.

This means, amongst other things, that the largely Anglophone international academic literature does not give a comprehensive account of research into science communication. In the interviews it also meant that, for example, Anglophone interviewees had little knowledge of the work of their Francophone counterparts, or of how extensive science communication scholarship is in German-

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<sup>3</sup> Note that we do not attribute quotes to speakers from specific national contexts in order to protect anonymity: the smallness of the field in some European countries means that it would be possible to identify interviewees based on the country in which they are based.



speaking countries. Interviewees tended to have more detailed knowledge of their immediate national context, in terms of scholarship and of the landscape of practice, than of international research, creating a moderate ‘silo’ effect. As one interviewee cautioned:

the field is very highly differentiated. [...] It’s taught and researched and thought about in very different ways in the French language zone, in the German language zone, and the English language zone, and so on. [...] It’s actually remarkable in a way that the science communication field is as highly internationally networked as it is.

Third, it was also apparent that interviewees came from, and worked within, diverse disciplinary, epistemological, and ideological positions. Those we spoke to came from the natural sciences, from science communication practice or journalism, from sociology, or from cultural studies or STS (science and technology studies); they mentioned, when discussing concepts they used or traditions they worked in, fields from psychology to history to communication studies to anthropology. There was no single set of theories, concepts, or approaches that was repeatedly referenced when participants were asked about the intellectual tools they drew upon in their work. One interviewee, for instance, said of the field that:

...that lack of both intellectual development and intellectual coherence actually, [means] it’s still not quite there. Because it’s a field that is very heterogeneous and attractive to scientists who have a very different methodological paradigm, I suppose, that they’re working within. People are coming at the research from very different fields.

Science communication might therefore be best described as a multi-discipline (Priest 2010), in which scholars from different traditions work on the same topic. What is particularly significant here is the quite profound differences between the various approaches that were cited and the implications this had for how individuals thought about science communication. They disagreed, for instance, about how knowledge (about science communication) could be robustly produced, the aims of science communication research and practice, and what the most urgent problems and research needs were. One interviewee said that “we have good literature in science communication” and that there were no important gaps; another that “there is too little theoretical development in the field”; others again suggested the key need was more large scale empirical studies, while other interviewees argued that too much research was just “repeating [earlier work], just with slight tweaks to the question or changes of country context”.

A key instance of this diversity is how participants thought about the purposes of science communication. For some science communication is fundamentally about “increasing knowledge and understanding” or ‘giving back’ to taxpayers, for others it was primarily understood in terms of questioning powerful interests, enabling citizen empowerment, or ensuring that science is responsive



to public needs and values. They had very different ideas, in other words, about what ‘good’ science communication should look like, and the stance it should have towards science.

### 2.3.3: Central challenges and concerns

Giving an overview of science communication knowledge in Europe is therefore not straightforward: it will depend on who you ask. Scholarship exists in a number of different domains and contexts that are only lightly networked with each other. However, despite the diversity of interviewee accounts, it is possible to trace a number of repeated concerns or priorities. These topics were mentioned by several – though never all – interviewees; they are outlined below.

First, social media was repeatedly framed as an important topic to understand more about, often within a broader constellation of issues such as public trust, expertise, and ‘post-truth’ societies. Interviewee comments included that:

a big area for research in future is understanding how people understand information in relation to science online and that sort of issue. The related issues of trust and expertise and how that's evolving and how science communicators navigate that new world.

Key challenges for science communication research were social media, moving beyond normativities, and examining the rise of science communication as ‘PR’.

the things that are happening on social media, faking the news and all the information flow that happens there, research on that is very interesting. This area is changing so quickly.

Again, the need for research in this area was framed in different ways by different people: for some, it was about understanding how science communicators might tweak their practices in order to help change opinions or behaviours, while for others it was more connected to understanding the role of social media in society or in democracy more generally.

Second, several interviewees raised concerns about the form that science communication (research) took and the purposes that it had. Some mentioned the field’s (partial) rejection of what is known as the ‘deficit model’,<sup>4</sup> but others simply argued that the notion that providing facts will change behaviour is widespread but problematic. This is one interviewee describing assumptions she has to educate trainee science communicators out of:

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<sup>4</sup> One of the relatively few conceptual frames mobilised in (some) science communication scholarship: see Irwin & Wynne 1995; Trench 2008 for a discussion.

the only discourse they can do on science is a normative discourse. Science tells you to do that, to do that, to do that. And the second thing [is] just by telling something about science people will immediately adopt it.

For this interviewee's students, science communication is about transferring information and thereby changing behaviour; for her, however, as well as other interviewees, this instrumental approach is not only simplistic and inaccurate but unhelpful. In this view, science communication's role in society was more concerned with "sense making" about the world or as an aspect of culture. Scholarship therefore needed to divorce itself from normativities (e.g., that science is necessarily better than other forms of knowledge) and instrumentalism (e.g. that science communication research should aim to help improve science communication practice) and examine science communication in broader terms, as in the following quotes:

talking about the role of science communication as a kind of service to science is a very restricted sort of view of it. This is also potentially a very restricted view of what science communication or science communication research.

Science communication usually is just the transmitting of science concepts, or scientific findings into, what we call the public scene. And this is a very limited view on science communication ... several times, I have said to the [national researcher funder] that they should stop funding these kinds of activities, stop it completely.

Third, several also interviewees also reflected, with concern, about science communication as (increasingly) taking the form of advertising, branding, or public relations. Too often "we reduce science communication to institutional marketing and branding", said one interviewee. Or, similarly:

that's a general problem, that the institutions, they're thinking that science communication should be reputation building. And if that's the aim, they then get a completely different kind of science communication.

Though this might take the form of the increased use of university advertising and branding – for instance on websites or in public adverts or merchandise – this concern about science communication as PR was not limited to activities that might be labelled as institutional publicity, but about the way in which science was discussed and promoted in the media. "I think it's important", said one interviewee:

that science communication leaves the public a bit more critical towards a lot of the research and research activities that are going on. And that we're getting a kind of critical eye [...] I see quite that quite a lot of science communication in the media often acts as a kind of podium for researchers. So the critical voices are often absent.

Or, similarly, one interviewee emphasised science communication's role in developing 'critical thinking' as part of supporting democratic debate:

you need to have some critical thinking skills in order to comply with that role of the voter. So again, science and technology contribute to the development of those critical thinking skills, I think. But that's just one answer, out of the million perhaps about why science communication is important.

As we will see in later sections of the report, this concern is one shared by at least some practitioners.

## 2.4 CONCLUSION

This section has explored the current landscape of research into science communication across Europe. The emphasis has been on how this is characterised by key scholars and educators in the field. After a brief survey of how science communication has been defined and modelled in academic literature, we have observed that: there is little evidence that science communication is a coherent research field; that it is constantly shifting as different centres and individuals rise to the fore; and that it is fractured along lines such as national context and disciplinary affiliation. Though there was no consensus regarding key challenges or research needs, social media were mentioned repeatedly, as was a sense that the field needed to move away from an instrumental approach (oriented to changing behaviours) and to embrace a more critical role in assisting interactions between science and society.

# SECTION 3: CONTEMPORARY SCIENCE JOURNALISM IN EUROPE: TAKING STOCK

## 3.1 INTRODUCTION AND METHODS

This third section of the report provides an overview of contemporary science journalism in Europe and is based on three research activities. First, an overview of literature on science journalism today, aiming to review this extensive field by synthesising major recent literature reviews. Science journalism is a key subfield within science communication and has been studied in depth for many years (see, for example the following books: Angler, 2017; Bauer and Bucchi, 2008; Bucchi and Trench, 2014; Nelkin, 1987). Our literature search focussed on an overview of the latest scholarship in this area to capture the important and enormous changes in journalism practice and consumption in recent years, with the advent of digital production, social media, web 2.0, web 3.0. Second, mindful of the studies already undertaken researching media coverage of the three QUEST topic case studies (Climate Change, Vaccines and Artificial Intelligence) we conducted more targeted literature searches to ascertain what existing scholarship about media coverage of these three topics has found. Third, we conducted 18 semi-structured interviews with a range of experts engaged in science journalism from across Europe. Interviewees were identified through a desk-based survey of science correspondents, journalists and editors in major media outlets; consultation with QUEST partners and snowball sampling techniques (Bryman, 2012). Informed by the literature review, we devised an interview question schedule according to the project Work Packages and in discussion with QUEST partners. The interviews were transcribed and analysed. The data were used to generate codes, similar codes were clustered together to form categories, redundant codes were removed. From these clusters of codes or categories we identified themes (Saldana, 2016). We report on the results of the literature reviews and interviews below.

## **3.2 THE LANDSCAPE OF EUROPEAN SCIENCE JOURNALISM RESEARCH: THEMES FROM LITERATURE**

### **3.2.1 Overview**

There has been an ‘explosion’ of research on how the media covers science since the 1990s. This research into media coverage of science journalism has focussed predominantly on coverage of natural sciences, coverage in Western countries and coverage in print media (Schafer, 2011, 2012).

#### **3.2.1.1 The Role of Science Journalists**

Much of the literature is concerned with the role of the science journalist. Scientific research is described as having historically distanced itself from society through a highly specialized approach and methods of communicating to itself leading to a conceptualization of scientific knowledge as being superior to other kinds of knowledge (Bucchi, 1998; Schafer, 2011) and concerns about a lack of science literacy in the general public. Science journalism has been seen as a way to address this as part of a movement called the ‘Public Understanding of Science’ or PUS (Gregory and Miller,

Literature on science journalism offers a number of roles for science journalists. Such journalism may be ‘routine’, and rather uncritically report on and cheerlead for science and scientific discoveries, or ‘mediatized’, where a more critical stance is taken. Science journalists have established their own professional set of routines and standards.

1998) which arose in the late 1980s and early 1990s. There is much debate about the role of science journalists as part of a PUS model and criticisms have been rife – leading to new models in which public dialogue or public engagement, as well as the more one-way, deficit model of PUS, can take place (Weigold, 2001; Schafer, 2011; Secko et al 2015). Many studies exploring aspects of science journalism repeat the claim that the media is the main source of scientific information for both citizens and decision makers (see for example, Weigold, 2001; Schafer, 2011, 2012; Rosen et al, 2016; Guenther et al 2019).

Science journalists are often accused of being too close to sources and uncritically reporting scientific research, without seeking a second opinion on its findings (Jensen, 2010; Schunemann, 2013; Williams and Gajevic, 2013; Dunwoody, 2014; Guenther et al 2017), seeing their role as explainer and communicator of complex scientific issues (e.g. Blobaum, 2008) instead of watchdogs of science. However, Rodder and Schafer (2010) argue that an increase in science coverage in the media has been followed by heated debate, with counter-experts and non-scientific actors lobbying for their point of view in media outlets. They report increasingly critical perceptions of science and technology by the public. Overall there is ambiguity in the academic literature over science journalists’ ‘proper’ role(s), and acknowledgement that they can and do fulfil more than one role in science communication (Secko

et al, 2015), and this may depend on both the social and political context of the country they are working in and the kinds of science stories they are producing.

Some clarity emerges from Rodder and Schafer (2010), who see two distinct forms of science coverage – ‘routine’ which rather uncritically reports and cheerleads for science and scientific discoveries and ‘mediatized’ when a more critical stance is taken. This more mediatized coverage is more often written by non-science journalists and appears in non-science sections and in tabloid media (Schafer, 2011). Rosen et al (2016) similarly argue that the role of science journalist can be both critical watchdog as well as uncritical cheerleader depending on the circumstances. Schafer however, (2009), suggests that this issue is in flux and that “claims of medialization, that is, of a change in mass media coverage leading to more extensive, plural, and controversial coverage, have to be specified and put into perspective.” (Schafer, 2009 : 496). Trench (2008) argues that the ‘deficit’ and ‘dialogue’ are not opposing models but part of a continuum or framework which can help to explain the multiple roles that science journalists inhabit.

### **3.2.1.2 Who are Science Journalists?**

There is a distinction made in research in this area between general journalists who, as part of their job covering news, are expected to cover science, and specialist science journalists who only cover science stories (Gregory and Miller, 1998; Weigold, 2001).

Specialist science journalists have been shown in the literature to be predominantly male, and highly educated, although not necessarily in science (Kristiansen et al 2016; Weigold, 2001). Bauer et al (2013) suggest that men hold the majority of science journalism positions in Europe, Africa and Asia, although women accounted for 45%. There are concerns in the literature about differing backgrounds, approaches and perspectives of journalists versus scientists (Schunemann, 2013; Secko et al, 2015) and their working practices e.g. scientists inch towards consensus over many years while journalists work to short deadlines and seek exciting, new ‘big discoveries’; journalism comes from an arts and humanities perspective while science comes from a natural and social science perspective. Science journalists are said to have a low status in the newsroom and are distinct from other journalists in several key ways: they are pro-science, with a personal interest in the subject (Schafer, 2011). The literature suggests that science journalists in the digital age are expected to work in a variety of media and across platforms (Dunwoody, 2014; Secko et al, 2015). In common with other areas of journalism, time pressure is reported to be an increasing problem – making verification or fact checking and investigation of stories more difficult (Schunemann, 2013).

While science coverage broadly speaking follows journalistic norms, literature reports that science journalists have established their own professional set of routines and standards (Guenther et al 2017). Evidence of this can be seen through the increasing organisation of the profession during the 20<sup>th</sup>

century, when Science Journalists' Associations and corresponding meetings sprung up leading to the founding of the EUSJA (European Union of Science Journalists' Associations) in 1971 (EUSJA, 2019) and The World Conference of Science Journalists which began in 1992 (Cornell, 1999; Dunwoody, 2014). However science journalists have always constituted a small subset of specialist journalists, and Weigold (2001) suggests science journalists, through professional associations and meetings, are more collaborative and homogeneous in their views about their work than other specialist journalist groupings.

Some literature argues that the late twentieth century decline in 'legacy media' and increase in online coverage, saw a corresponding drop in dedicated science sections (Dunwoody, 2014) and a decrease in science journalists (Schafer, 2011; Rosen et al 2016; Guenther et al 2017). This literature reports that science tends to be a low priority for most media compared to other subjects such as politics (Weigold, 2001; Schafer, 2011), however, there is disagreement in this area, with Badenschier and Wormer, (2012) arguing that science coverage has a higher media profile since the late 1990s; more recent reports suggesting that science journalism is increasing in proportion to coverage of other subjects (Schafer, 2011; Kristiansen et al 2016; Summ and Volpers, 2016); and reports that the occupation of *science journalist* continues to grow, albeit in a freelance rather than staffer capacity (Dunwoody, 2014).

### 3.2.1.3 PR influence/role

While there is little agreement as to the current amount of science coverage in the media, the literature reports a definite increase in science public relations activity (Goepfert, 2007; Schafer, 2011; Schunemann, 2013; Williams and Gajevic, 2013; Guenther et al 2017). This is attributed to structural changes in research institutions, for example research funding becoming more dependent on public impact and increasing expectations that scientists will communicate with the media (Schafer, 2011). Science PR activity also increased in other organisations e.g. industry and NGOs with a lobbying function. Weigold (2001) and Duke (2002) argue that press officers and other science public relations specialists feel they play an important role as 'informed translators' for journalists. In addition, Duke, (2002) reported an increasing use of email by journalists and by PR professionals trying to contact them, and a continuing increase in both science PR activity and reliance on it by journalists (Rosen et al 2016). However, there is widespread concern about the undue influence wielded by an ever growing science PR machine over a potentially shrinking pool of science journalists and the impact this can have on the independence of science journalism and science journalists' ability to properly interrogate science policy and findings (Goepfert, 2007; Dunwoody, 2008; Williams and Gajevic, 2013).



#### **3.2.1.4. How is science framed in the media?**

With an unprecedented amount of source material to choose from, and frequent accusations of inaccuracy, sensationalism and simplification (Schafer, 2011; Schunemann, 2013; Secko et al, 2015) it is perhaps not surprising that science journalists reportedly rely on a small number of influential journals (Schafer, 2011; Rosen et al 2016) where they can be sure the quality selection process has been done for them (Schafer, 2011; Schunemann, 2013; Dunwoody, 2014) through peer review. The implication is that many science journalists rely on key gatekeeper sources, and are less likely to challenge science, or report the process of scientific research, instead waiting for the peer review process and reporting the scientific mainstream.

Several authors argue that science reporting has its own news values (Gregory and Miller, 1998; Weigold, 2001; Badenschier and Wormer, 2012; Guenther et al 2017; Rosen et al, 2016). Firstly and overall, different disciplines within science are not equally reported, with medicine/health and biology currently dominating science coverage worldwide (Schafer, 2011; Badenschier and Wormer, 2012; Dunwoody, 2014). Bucchi (1998) and Weigold (2001) raise the important issue of definition of science – noting that both journalists themselves and the academic literature about them and their coverage do not agree on a definition of science. Some scholars argue that any and all academic research should be included, while science journalists themselves are reported to focus mainly on their own subject specialism or areas of personal interest, or exclude particular areas, such as Technology (Weigold, 2001, Rosen et al, 2016). Overall there is a focus on reporting results and less attention paid to methods or process (Dunwoody, 2014; Suljok et al 2013).

According to Badenschier and Wormer (2012) science only makes the front page if it relates to politics. Equally, politics crowds out science coverage. They report that as well as political interest the ‘surprise factor’ is important, along with usability for the reader – news that they can use. Similarly Dunwoody (2014) found that science coverage uses news pegs such as timeliness, conflict and novelty, because these help to sell stories to an editor, sell newspapers from the stand or garner clicks.

### **3.2.2 Literature on media coverage of topic case studies: Climate Change; Vaccines; Artificial Intelligence**

#### **3.2.2.1 Climate Change**

Of the three QUEST case studies, searches for literature examining how the media covers climate change returned the most results, with a lot of literature coming from many different countries over a long period of time. Both Anderson (2009) and Schafer and Schlichting (2014) date this interest back to the early 1990s and note a considerable rise in scholarly interest since 2008, although the focus has been on European and North American countries, and print media dominate.



Overall the literature presents this as a contested area. Concerns are raised about concentration and globalization of media ownership as well as growing PR influence (Anderson, 2009) and ‘balanced’ reporting which has given undue weight to climate change deniers (Boykoff and Boykoff, 2004; Boykoff 2007). These are linked to tensions about how risk is presented (Carvalho and Burgess, 2005), how and by whom scientific facts are defined and how strongly these definitions are linked to ideologies (Carvalho, 2007; Lonsdale, 2013; Williams, 2015). Drawing on the work of Downs (1972) the ebb and flow or Issue Attention Cycles in coverage are noted in this research context (e.g. Djerff-Pierre, 2012). Peaks are reported to relate to triggering events (Anderson, 2009; Schafer, Ivanova and Schmidt, 2014) such as international climate conferences and the influence of celebrity is also noted (Boykoff and Goodman, 2009; Anderson, 2011). The subject has entered the mainstream but the time frame implicit in the research makes it difficult for reporters to sustain interest from audiences and editors (Anderson 2009; Lonsdale, 2013). Due to the time lag inherent in academic publishing, recent developments such as the impact of activist Greta Thunberg have, to the best of our knowledge, largely yet to be reported.

### **3.2.2.2 Vaccines**

A large amount of literature exploring how the media discuss vaccination was found. However, unlike the literature on climate change, this was very fragmented, with media coverage about different types of vaccine, for example the MMR, (Measles Mumps and Rubella), influenza or HPV (Human Papillomavirus) vaccines being often researched in isolation. This makes the literature in this area difficult to review, although at least one recent paper (Catalan-Matamoros and Penafiel-Saiz, 2019) attempted a systematic review.

Like climate change, vaccines were acknowledged by the research as a controversial area in the media – this was particularly raised in relation to the influence of social media on the topic of vaccines (Jang et al 2019). In addition, there are some similar and related concerns for example the question of balance (Clarke et al 2015; Catalan-Matamoros and Penafiel-Saiz, 2019) in this case between those in favour of and those against vaccination programmes. Researchers raised concerns about accuracy in reporting and a lack of useful and practical patient information e.g vaccine safety; potential side-effects and follow-up appointments (Habel et al 2009).

### **3.2.2.3 Artificial Intelligence**

In comparison to both the QUEST case studies of Climate Change and Vaccines, little literature on media coverage of Artificial Intelligence (AI) was found. We found that the separate issue of the use of AI in journalism to produce automated journalism or robo-journalists, (see for example, Anderson, 2018; Angler, 2017 and Thurman et al 2017) has received much more research attention than how AI

is reported in the media. Our searches showed that such literature as there is on media reporting of AI is recently published and mainly concerns the prominence of industry and their products in much of the reporting (Brennan, Howard and Nilesen, 2018); AIs portrayal as a general solution for societal challenges without acknowledging AIs capabilities and limitations (Brennan, Howard and Nielsen, 2018; Roff, 2019); and the tendency for media to treat AI as a new or future phenomenon despite its longevity (Bory, 2019).

Many of the themes identified in the literature on both science journalism in general and on the media coverage of the QUEST case studies are echoed in the interviews we conducted with those involved in science journalism - these are reported below in section 3.3.

### **3.3 CONTEMPORARY EUROPEAN SCIENCE JOURNALISM PRACTICE: KEY THEMES FROM INTERVIEWS**

Compared to the interviews with science communication scholars reported in Section 2 above, there was a relatively high degree of consensus among participants regarding journalistic processes and routines. There was little general differentiation in terms of practice between journalists working both in different media (working in either a primarily broadcast, print, or online context) and those working in different country contexts. While it was noticeable that the national political contexts within which journalists were operating were different, and this had some impact on journalistic output as discussed in Section 3.3.4 below, specialist journalists covering science talked about many of the same routines (for example the sources they used, their journalistic norms and processes) as well as similar enablers and challenges they faced in the course of their work. Several of the journalists we spoke to, regardless of the primary medium they worked in, reported working across media including broadcast, print and online as well as making use of different digital formats for example podcasting, blogging or vlogging. They were expected to write articles as well as appear in front of and/or behind the microphone as part of their job, whether they were staffers or freelancers. In addition, some authored science books alongside their media work. Below we report on the major themes arising from these 18 interviews.

There was a relatively high degree of consensus among interviewees regarding processes and routines. Science journalists reported working across different media and both writing content and producing it.

#### **3.3.1 Role of the Science Journalist**

Some important questions were raised by analysis of the interviews relating to the role of the science journalist both in the newsroom and in society.

First, given that the focus in participant recruitment was specialised science journalists, we expected a high level of science knowledge, and a different approach to that of a general journalist working in a newsroom in that participants who were specialist science journalists only reported science stories. However, we found that many of the journalists we spoke to, while identifying as science journalists, tended to specialise in a specific area of science and were wary of straying too far from their area of expertise or interest. The following quotes are from a British and an Italian science journalist respectively:

Interviewees were not in agreement about the role of the science journalist. Several argued that science journalists' role was not to confine their reporting to simply translating complex science or giving a platform to new discoveries. Rather they should go beyond translation or cheerleading to investigate science policy and funding and challenge 'bad science'.

I mean there are just certain areas that don't interest me and so I just don't touch them. Computing and AI I suppose is one, is a good example. And that's not to say there are not good stories there but they're not for me.

Vaccines is medicine and I steer clear of medicine, it's not my...I have a pet peeve, if I may say so...because if I have to study too much that means I'm not prepared on the topic and therefore I prefer to avoid it.

This begs a question about the nature of science reporting that is echoed in the literature on science journalism: in order to define a science journalist, how do we define science? And what subject areas should it include or exclude?

Second, there was a tension between those that felt science knowledge was a primary skill for science journalists, while others felt that journalism skills and experience were more important than a science background. Several of the interviewees, while acknowledging the importance of science knowledge and "science literacy" as an aspect of quality in science journalism and a key tool for science journalists, felt that many, if not all, stories in the news had an element of science that it was important for journalists to explore. A UK based science writer commented:

I mean, so much of news we consume, has a science angle broadly defined. I mean you know virtually any article on food nutrition [laughs], you know that's all health right? The same goes increasingly for stories related to technology or the way in which technology is affecting social interaction and our mental health so [laughs] it's enormous.

And a British science press officer agreed:

You can't move for science coverage, it might not necessarily scream science when you first read it, but the biggest stories of the day like Grenfell Tower, Charlie Gard, Billy Caldwell getting his cannabis products confiscated, the Huawei security threat all of those have science at their heart and we would class those as science stories as well as a new species has been found or space and black holes like all of that stuff that's very obviously science

This raised concerns among some, but not all participants, about a perceived lack of science knowledge in non-specialist journalists:

I think that if one has to write something or to communicate something on my topic, so evolution, or vaccines or AI, or whatever, he or she needs to have a very solid background in order to understand the science paper. And in order to um...make interviews, really deep. Because otherwise the interviewee will fool you of course. (Italian science journalist)

I think that's probably one of the main things that can be quite tricky for general news reporters to get their head around quickly. Especially if there's a really tight deadline and just understanding what the study's actually showing there's also just so many studies, so much evidence, so much science that's been published, that sort of to get your head round a single field and what studies are significant in the field - and what are sort of just repeat experiments, finding repeat findings and sort of just replicating previous studies and what really are the big new studies in the field. (British science press officer)

If I could wave a wand...I would really make sure you had a science module where you were taught about the scientific method, about how to read a scientific paper, um and about statistics, about weight. I really would. I think it's fundamental. (British science journalist)

However, some participants, as mentioned above, felt that journalism skills were more important than science knowledge, especially as science journalists were expected to cover such a broad field and could not be expected to be specialists in every area of science.

Third, interviewees were not in agreement about the role of the science journalist. Several argued that science journalists' role was not to confine their reporting to simply translating complex science or giving a platform to new discoveries. Rather they should go beyond translation or cheerleading to investigate science policy and funding and challenge 'bad science'. However, several commented on the barriers that can prevent journalists from doing this:

On the magazine I mean I'm stuck on my desk and I cannot go around doing let's say 'real journalism' let's say. In this case I'm more a translator, more a communicator. But if I have time and money my desire will be to be a watchdog. (Italian science journalist)

I was criticized by a number of science journalists that this is not science journalism what you're doing because science policy should not be in science news...this is policy or financing and this is not what you should cover in science news. But now four years later what we found is that our news platform has also become a news platform for scientists and politicians to get their topics discussed there regarding the science policy and funding. (Estonian science journalist)

You know I call it a bit like the doctor's syndrome....I mean they are God-like. And at times scientists can be seen like that as well. You don't challenge them. And the best way perhaps for a journalist to do that is to challenge with a "really? I don't understand." Because actually most of what they say a lot of the journalists don't understand, but pretend they do. (British media consultant)

### 3.3.2 Key enablers and barriers to quality

Analysis of the interviews revealed several areas of concern and some areas where improvements were noted.

#### 3.3.2.1 Science Literacy

As noted above “science literacy” was a key concern for many interviewees. This was mentioned in relation both to the importance or otherwise of levels of science knowledge and education among journalists and among audiences. A lack of journalists with a science background entering the profession was an issue for some, while others lamented a lack of science knowledge among the general population. However, lack of “scientific literacy” among the audience was not, for some, like this senior science editor as much of a concern since the role of the science journalist was to engage and educate viewers, listeners and readers:

Key areas of concern with regard to the quality of science journalism were scientific literacy (in both journalists and their audiences), reduced funding, and relationships with sources.

There's a certain trepidation about science that they feel it's too complex for them to understand and in many ways science is quite simple and straightforward and so it's trying to make it easier and make it accessible for those people is, is, is a task that I am set, and one that I've tried my best to get to grips with.

However, some felt this could lead to a ‘deficit model’ of science communication (Trench 2008), for example from this interviewee, a senior media consultant, who sometimes felt talked down to by science journalism:

It's a bit like I know a lot, and you clearly are a moron and you don't know. Or, or I'm treated like as if I have the same PhD as the scientist who did it, and then it completely goes. So it's either that there's a degree of patronising, or it totally goes...So to me it's about that. It's about actually get the balance between intelligence and knowledge, respectful intelligence and knowledge.

In terms of the ability of journalists to present science stories in a way that is engaging some felt the advent of new technologies and multi-media digital tools and techniques had supported them to prepare more attractive and absorbing reports, and that their media organisations had successfully invested in new technologies. However, several felt their organisations or they themselves had fallen behind in embracing new technologies. These quotes from an Italian journalist and a British editor:

Every science journalist should try to improve his or her knowledge of technology of communication...Because, just for me, I mean I need to study much more the communication of science communication, in order to have a better impact on the readership and maybe on my colleagues. I mean it's my opinion. Just for myself. I need to be much more familiar with the tools and technology and the science of science communication.

It's all about diversifying your content types, right? And we haven't gone as far down the road as we need to. And we're having interesting conversations now about making sure we don't become a dinosaur. And how we get the next generation of readers to be coming in.

### 3.3.2.2 Funding

A key area of concern mentioned by many of the interviewees was the issue of funding. All areas of journalism have been experiencing funding issues related to a decline in circulation of newspapers and magazines and this income not being replaced by online models of journalism (Cairncross, 2019). Cutbacks in staff, programme budgets or freelancers' fees were commonly mentioned by interviewees. Several interviewees were concerned that science journalists were at the front line of newsroom cuts. Related and perhaps of more specific concern to journalists writing about science was the perception of an increase in Public Relations activity by those involved in scientific research or the promotion of science. There was a perception that numbers of science press officers or public relations personnel had increased in relation to the numbers of science journalists, and that these two issues were related, in the sense that, as one interviewee put it: "I think just the professionalization of marketing and PR in the universities means there's a talent there of science writers who've gone into PR rather than become journalists...For society I think it's a bad thing."

Interviewees working as science journalists reported unmanageable numbers of emails from press officers, overwhelming their email inboxes. There was concern about the quality, relevance and usefulness of these. These quotes are from an Italian health writer, a senior UK newspaper science journalist, and an Estonian journalist:

Yes we receive tons of press releases every day and tons of phone calls from media offices and so on.

Oh Christ! I get hundreds of emails a day, yeah. And most of its complete bollocks. So it's quite easy to deal with. Er, um, I mean you just, I mean I've got about three or four hundred a day, most of its press releases.

My inbox is also full although those press releases and information pieces they are sent by the science communication from the universities and research agencies and so on they usually cover like we have a conference going on or we have a seminar this or we have published a book I don't care about the event I want to know about the content!

Some were concerned that a more general journalist without specialist knowledge, working to a tight deadline, would not be able to distinguish between press releases announcing high quality robust science and those that do not and would be tempted by an “inflated” science story. One interviewee raised concerns about the blurred lines between science journalists and science press officers – with freelance science journalists frequently fulfilling a dual role of journalist and communications officer, with a potential conflict of interest arising. There was a general sense that specialist science journalists set themselves apart in some ways from other journalists, and that they should be called upon if science expertise was required, for example to verify a science story or decide if it was worth covering.

### 3.3.2.3 Sources

As specialists frequently looking for a story that was not part of the general news cycle; a story that nobody else had, specialist science journalists talked about their relationships with scientists. Trust was considered important in this respect and journalists talked about the efforts they made to keep up with scientists in their field. Several interviewees mentioned an improvement in access to scientists, many of whom had become more willing to talk about their research to the media, in order for their research to have impact, particularly if they trusted the journalist they were talking to. Those journalists who had been working in the field for a long time talked about ease of access to scientists being related to improvements in communication for example email, which overcame international time differences etc. However, there were still some concerns that increased levels of science PR introduced barriers to direct access to scientists for journalists.

Some key sources of information and stories and therefore key gatekeepers to science news emerged. The magazines Nature and Science were mentioned alongside the science news service EurekAlert! These featured regardless of country and as required reading, almost as a baseline of information or knowledge about science news.



#### **3.3.2.4 Guidelines**

In the area of guidelines for science journalism some differences between countries emerged. Italian journalists talked about a professional register of journalists working in Italy run by the Order of Journalists (Ordine dei Giornalisti, ODG, 2019) where journalists must register before they are allowed to practice. Journalists in other countries talked about general journalistic good practice and codes of ethics and felt that science journalism did not need special guidelines, it should follow the principles of ‘good journalism’. While several welcomed the idea of further training for science journalism, in terms of being able to understand as one interviewee put it “the language of science”, some were wary of specific guidelines beyond more generic journalistic good practice, feeling that these would be too rigid and could constrain the freedom to report, or be easily overtaken by new technology.

### **3.3.3 The case studies**

All interviewees were asked about their experience of reporting on the QUEST case study topics. As noted above in section 3.3.1, many of the interviewees specialised in specific areas of science and so not all had covered all three topics. The topic most commonly covered was climate change, followed by vaccines. Few of the interviewees had reported on artificial intelligence.

#### **3.3.3.1 Climate Change**

Interviewees mentioned that this had been an area of controversy and that interest both from editorial staff and audiences in the subject area had fluctuated over time, echoing evidence in the literature, dating back to the Issue Attention Cycle (Downs, 1972). Several commented that they were more able to cover the topic due to increasing concerns about the effects of climate change (e.g. extreme weather events); a renewed importance in the news agenda of the topic due to high profile campaigners (e.g. Swedish activist Greta Thunberg); scientific consensus and high profile reports (e.g. IPCC). Despite this some science journalists still reported correspondence from climate change deniers, some of it aggressive and intimidating.

#### **3.3.3.2 Vaccines**

Similarly, the topic of vaccines was considered by several participants to be, as one interviewee put it a “highly emotionally charged” subject. They reported high levels of audience correspondence from both ‘anti-vaxxers’ as well as those who supported vaccination programmes. This, and the sense that this issue had a direct impact on personal, family and community health lead to an increased sense of responsibility on the part of the reporters, as outlined by this British science writer:

Well I'm hyper aware of I mean this goes for all journalism but it's even more important for writing about a subject that potentially can affect people's lives you know you've got to be really precise and



accurate with what you write and that means on the one hand pointing out all the benefits of vaccines and the risks and why they on the whole are a positive thing.

However many reporters were aware that however responsible their reporting, audiences were also exposed to a lot of information from other sources that was perceived as more emotional and less evidence based for example on social media such as Facebook or from friends or family members in closed WhatsApp groups. There were differences in the country contexts in reported influence of an anti-vaccination movement and the perception of problematically low take-up of vaccination programmes for example in relation to measles. In Norway and Estonia this was not considered by participants problematic, unlike in Italy and the UK. However, reporters recognised that social media content for example by anti-vaccination movements was not governed by geographical boundaries and could easily spread between countries.

### 3.3.3.3 Artificial Intelligence

As noted above fewer of the journalist participants had direct experience of covering artificial intelligence. Asked to comment on reporting about AI, interviewees commented on its poor definition and its general overuse as a term. Interviewees felt AI was a ‘sexy’ subject and because of this was often mentioned in science and technology reports, even where technology being described could not actually be defined as AI. As one interviewee put it: “I think AI is a very broad term and I think even AI researchers can’t agree what AI is so that’s the first major issue. I think if you want a sexy story you say it’s AI now and it might not be.” A concern raised by two interviewees was that much AI research was funded by private companies and therefore not publicly available. AI reporting was described as fitting particular frames: a ‘futurism’ frame – with reports speculating on what it might achieve; framed in terms of ethics regarding the ethical implications of for example driverless cars; or framed in terms of alarm with regards to job losses due to an increase in machine learning and mechanisation.

### 3.3.4 Emerging issues

Trust and fake news were emerging issues that journalists saw as particularly important.

Interviewees were asked about emerging issues of concern relating to science journalism. An area not already raised in this report concerned issues of trust in science journalism, and in science and scientific experts more generally. This was related to changing political contexts and was frequently mentioned in connection with the phenomenon of ‘fake news’. Some journalists reported a

worrying increase in personal attacks on them via social media, because of the science they were reporting. These quotes come from an Estonian and a British interviewee:

As you know we [in Estonia] have moved a step closer to the right, populist so to say and they are discrediting scientists and they are not using the research that is made available or made for them or for their decisions so we're actually moving a bit away from scientific or evidence-based society I guess and if this continues there might be growing distrust towards scientists.

The whole thing about fake news, the whole thing about deniers and so on. That will continue to challenge journalism in general. I think the current wave of the type of hatred politics and confrontation politics, is having an impact everywhere. And journalism is in the middle of this. And now whatever journalists write or say that someone disagrees with its fake news. It's not to disagree with it's fake news... And I think that will really grow and will be quite tricky.

### 3.4 CONCLUSION

The preceding section highlights some of the key issues facing contemporary science journalism. To some extent these are related to wider matters which confront the world of journalism as a whole - for example the disruption of established business models, rapid change due to digital innovation, sharp decline of print sales and especially print advertising, the overwhelming power of new platforms etc. The questions of verification and reliability of sources which face science journalism are also part of a wider framework of media and reporting that is dealing with a radically changed landscape and indeed a revolution in the production and consumption of news.

However beyond this our interviews and analysis highlighted particular issues which are encountered by science reporting - and many of these are evident in the particular case studies of this project. Science reporting is nevertheless an exciting and vibrant area where young journalists are offered a range of potential opportunities and which is the subject of interesting research and analysis. But significant issues such as the power of public relations and the question of scientific literacy pose inevitable problems and challenges which were very evident in the data and material presented here.

# SECTION 4: SCIENCE ON SOCIAL MEDIA: THE CONTEMPORARY LANDSCAPE AND KEY ISSUES

## 4.1 INTRODUCTION AND OVERVIEW

The advent of social media has changed the way in which we access information and form opinions (Zollo & Quattrociochi 2018a) and has led to a shift away from a traditional content production paradigm, in which mainstream media sources determine the content, frequency, timing, and medium of communications. Nowadays, news organisations have adopted social media platforms, such as Facebook and Twitter, as a means to distribute news and connect with their audiences. Furthermore, online readers are no longer confined to word-of-mouth communication after consumption: social media platforms significantly amplify their ability to communicate with each other and to provide feedback, thus changing their role in both information consumption and production (Zollo & Quattrociochi 2018a). Science communication has not been exempted from the changes introduced by this paradigm shift, with scientists and science institutions embracing public communication in the online world (Brossard 2013).

Much research has been done in analysing how social media platforms influence journalists (Hermida 2010, Lasorsa et al. 2012), and the (potentially polarising) effects they have on public opinion (Sunstein 2002, Del Vicario et al. 2016, Zollo & Quattrociochi 2018b, Schmidt et al. 2017). There is also research that attempts to understand how the digital age has changed science communication, with most work focused on the paradigm shift outlined above and therefore focusing on aspects of new media such as content production of blogs, bias in search engines, and the role of news aggregators (Brossard 2013, Brossard & Scheufele 2013, Mewburn & Thomson 2013, Davies & Hara 2017).

A more limited amount of research has been carried out on science on social media platforms. However, a considerable number of studies consist of surveys and (retrospective) interviews (Hargittai et al. 2018, Corley et al. 2011, Anderson et al. 2010, Huber et al. 2019, Colson 2011, McGowan et al. 2012, Knight & Kaye 2016, Collins et al. 2016, Su et al. 2015), lab experiments (usually performed on a relatively small group of people and prone to external validity issues; Hart & Nisbet 2012, Jaffar 2012), or very limited quantitative studies (Pearce et al. 2014, Lörcher & Neverla 2015). Save for a few exceptions (Runge et al. 2013, Kahle et al. 2016, Büchi 2017), science communication studies on social media platforms fail to take advantage of the large quantities of data that are now available. The majority of studies are limited to one topic (Schmidt et al. 2018), have short time frames (Lörcher &

Neverla 2015), focus on a single social media platform (Runge et al. 2013) and/or consist of small datasets (Pearce et al. 2014, Lörcher & Neverla 2015). This lack of quantitative research into science communication on social media platforms is surprising, considering the wide availability of information available on them (Brossard 2013).

This section aims to make use of massive quantitative analysis to take a snapshot of the current situation of science communication on online social media. The section considers social media use across different European countries, three social media platforms (Facebook, YouTube, Twitter), and a range of science communication content producers.

## 4.2 DATA SOURCES

We collected public data from Facebook, Twitter and YouTube. Specifically, we downloaded the content published by a set of accounts of public entities manually selected to be a good representation of science communication in Europe. Due to the fact that the Twitter data mining is restricted by a limit of 3,000 tweets into the past, the list had to be completed quickly in order to start the data mining process. The list was done manually, with the collaboration of QUEST partners, to represent a range of sources of science communication on social media across Europe as best as possible.

The sources are distributed across 7 countries (UK, Ireland, Italy, France, Germany, Estonia and Norway). Science communication sources that are not specific to one country are considered European, such as the European Research Council or the European Space Agency, since their content reaches a wide European audience. The list also sought to include different categories of science communication sources: Science Festival, University, Industry/CEO, Science Journalist, Institution/Organization/Association, Magazine/Publication (Online Included) and Scientist/Expert. The list also allows the sources to distinguish the three case studies of QUEST: Vaccines, AI and Climate Change.

The finished list includes 737 sources with at least one active account<sup>5</sup> on Twitter, Facebook or YouTube. The dataset has a total of 498 Facebook pages, 393 YouTube channels and 661 Twitter accounts<sup>6</sup>. To the best of our knowledge, the dataset is the largest science communication multi-platform to exist to date. Table 1 shows the distribution of accounts across platforms, countries and types of science communication sources. For a more detailed breakdown of the dataset please refer to Appendix B.

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<sup>5</sup> A science source can also be active in more than one platform as can be seen in the complete list of sources available on QUEST Data Repository: <https://rs.unive.it/?r=2937>

<sup>6</sup> The number of Twitter accounts present in the database (661) is the number of Twitter accounts present in the list (697) due to the fact that not all accounts were active during our download period.

Table 1 - Breakdown of the accounts per country, source type and social media platform. TW: Twitter, FB: Facebook, YT: YouTube. The different numbers across platforms is due to the fact that not all science communication sources are active across all three platforms.

Country		Festival	Industry /CEO	Inst./Org./ Assos.	Magazine/ Publication	Science Journalist	Scientist/ Expert	University	Total
DE	TW	4	4	15	16	20	11	24	94
	FB	4	3	14	15	1	4	24	65
	YT	3	3	13	8	1	3	24	55
EE	TW	1	3	4	2	1	4	7	22
	FB	1	7	10	10	0	1	12	41
	YT	1	2	5	2	0	1	7	18
EU	TW	3	2	40	8	3	2	0	58
	FB	2	1	31	7	0	1	0	42
	YT	1	1	30	3	0	1	0	36
FR	TW	5	10	16	12	25	10	19	97
	FB	5	7	16	12	4	2	19	65
	YT	3	8	15	8	2	1	18	55
IE	TW	7	11	11	8	12	6	8	63
	FB	6	6	10	6	3	0	8	39
	YT	4	6	10	4	1	0	8	33
IT	TW	7	13	40	32	32	28	16	168
	FB	7	10	38	36	15	13	17	136
	YT	6	9	35	21	9	9	16	105
NO	TW	0	4	14	7	6	11	12	54
	FB	0	3	12	6	2	5	10	38
	YT	0	2	9	5	0	2	10	28
UK	TW	8	3	27	17	19	44	23	141
	FB	7	1	19	16	6	2	22	73
	YT	4	0	18	12	2	5	22	63

### 4.3 DATA COLLECTION

The data collection process was performed exclusively by means of the Facebook Graph API<sup>7</sup>, the Twitter API<sup>8</sup> and the YouTube Analytics API<sup>9</sup>, which are all publicly available through one's account in the respective platform. The data gathered is all publicly available. Accounts with privacy restrictions were not included in our dataset. Moreover, in this project we used fully anonymised and aggregated data.

The Facebook data consists of 600 posts per year per account with their respective public metrics, i.e. number of comments, likes and shares. The posts were downloaded on June 30 2019. We also gathered all the anonymized public comments the posts received until July 22 2019.

The Twitter data consists of all Tweets published on the accounts in the list during the data collection period of April 1st 2019 to July 31st 2019. Due to the data mining restrictions of the Twitter API we don't have access to the replies received by the tweets in our dataset. Because of this, the sentiment analysis of the replies could not be completed.

The YouTube data consists of all the public videos published in the accounts listed with their respective engagement metrics and all their public comments. The video data was downloaded on June 30th 2019 and the comments were downloaded on July 22nd 2019.

### 4.4 DATA ANALYSIS

The analysis is structured according to social media platform and to our case studies, i.e., vaccines, AI and climate change. The data analysis includes quantitative analysis of the content creation over time (number of posts, videos or tweets produced), engagement, and concept extraction and sentiment analysis, done with the Watson Natural Language API<sup>10</sup>, that applies machine learning and natural language processing techniques to analyze text and automatically extract relevant entities and concepts, their semantic relationship as well as the emotional sentiment they express.

We make use of two metrics to understand engagement: the *overall engagement* and the *engagement volume*. The overall engagement is the total number of users who interact with a piece of content. It gives a general idea of the *audience size*. The engagement volume, on the other hand, is the number of users who interact with a piece of content while considering the number of users who follow the account that published it. It gives a general idea of how *engaging* the content is. As an example, one

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<sup>7</sup> <https://developers.facebook.com/docs/graph-api>

<sup>8</sup> <https://developer.twitter.com/en/docs/tweets/search/api-reference.html>

<sup>9</sup> [https://developers.google.com/youtube/analytics/?hl=en\\_US](https://developers.google.com/youtube/analytics/?hl=en_US)

<sup>10</sup> <https://cloud.ibm.com/apidocs/natural-language-understanding>

metric of overall engagement on Facebook could be the number of likes (or comments or shares) received by a post, while the engagement volume would be the number of likes divided by the number of fans of the Facebook page that published the post.

The Watson Natural Language API<sup>11</sup> analyzes a chosen text and returns a number of high-level concepts in the content given. For example, a research paper about deep learning might return the concept "Artificial Intelligence" although the term is not mentioned.

Sentiment analysis analyzes the general sentiment of the content, returning a sentiment polarity (positive, neutral or negative) and a sentiment score, a value ranging from -1 to 1, where 0 corresponds to a neutral sentiment, and the more negative or positive a value is, the more negative or positive the sentiment of the text is.

In what follows we describe top level findings from our analysis of the three different social media platforms and the three QUEST case study topics (climate change, vaccines, and AI).

#### 4.4.1 Facebook

Science communication on Facebook has increased since 2010. A large variety of topics are discussed. Pages engage a similar proportion of their fans regardless of country.

Science communication on Facebook increased over time since 2010, with accounts publishing much more frequently nowadays. Difference in use can be noted when considering the normalized posting frequency of the countries, with the UK and Italy publishing more than 150 posts per semester since the second semester of 2015, whereas the other countries published on average 117 posts per semester. German sources also have a tendency to post frequently when compared to the rest of the

countries, showing a large use of Facebook to communicate about science. Estonian Facebook accounts publish posts considerably less frequently than the other countries, with a mean of 52 posts per semester.

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<sup>11</sup> The concepts extraction and sentiment analysis features supports the languages English, French, German, Italian, Japanese, Korean, Portuguese and Spanish. Sentiment analysis also supports Arabic and Russian.



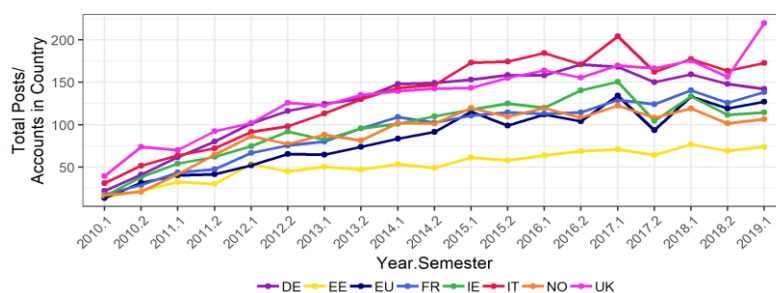


Figure 1 - Avg. Posting Frequency on Facebook Normalized per Country. Each semester shows the total number of posts published by each country in that time period, divided by the total number of Facebook accounts in that country.

In order to determine the main topics discussed during 2019, we ran the text of the posts through the Watson Natural Language API to obtain, where possible, three high-level concepts for each post. In the case of Norway and Estonia the number of relevant extracted concepts is low, due to the fact that Estonian and Norwegian are not supported by the Watson NLU software and that only posts in the supported languages were analyzed.

The majority of the concepts (99%) appear on less than 0.6% of the content of each country, that is, a concept usually repeats itself in less than 0.6% of the posts published by each country. This implies that a great variety of topics were mentioned during the first semester of 2019. The concepts that appear more frequently (in more than 2% of posts) are general keywords like *research* and *science* or location and institutions relative to each country like *karlsruher institut technologie*, *european union*, *united kingdom* and *dublin*. It's interesting to note, however, that in the case of France two very specific concepts appear with a frequency higher than 2%: *cancer* and *lune*<sup>12</sup>.

The list of words with frequency above 2% of total content and the wordcloud of the top 75 concepts of each country can be found in Appendix B.

We now look at the overall engagement and engagement volume in order to understand how many people interact with science content on social media and how involved they are when interacting with the content. (For corresponding graphs please refer to Appendix B.) The overall engagement of likes, comments and shares display significant differences in the audience size of the different countries. European pages are considerably more likely to reach massive audiences in contrast to the other countries. The EU is the most likely to get 10.000 or more likes, comments or shares (and is also the most likely to get 1M likes on a post). After the EU, the UK is the second most likely to reach large audiences, when considering all three metrics (likes, comments, shares). France also has a high probability of reaching big audiences when it comes to likes, as does Germany when looking at comments and Italy when looking at shares. Estonia and Norway both have limited reach, and are very unlikely to get more than three thousand likes on a post.

<sup>12</sup> Moon in French.



While the possible reachable audience size by each country on Facebook differs significantly, the engagement volume is very similar. That is, pages engage a similar percentage of their fans (people who liked the Facebook page) regardless of the country. Only three countries pop out across all three metrics when looking at engagement volume: the UK, for being slightly less engaging than the rest, and Estonia and Norway for being slightly more engaging than the rest.

Once we know interest in science communication in each country, we focus on the different types of science communication sources, i.e. universities, science journalists, scientists and experts, magazines and publications, industry and CEO's accounts, science festivals, and institutions, associations and organizations. (For a detailed chart on this analysis please refer to Figure 13 in the Appendix). When considering the median engagement volume for each country and source type pair we find that, in terms of likes, Science Journalists from Ireland, France, and Germany, as well as Scientists and Experts from Norway, Italy, France and Germany, manage to engage their audience to interact with them quite a lot. German and French festivals are more likely to engage users to give them likes than the UK, Italian and Irish Festivals. In Industry/CEO and Institutional pages we observe a variety of engagement volumes in terms of likes, with UK being very engaging in the first type and Estonia and Norway in the second.

When considering median engagement volume of the comments, we find that it is 0 in the majority of the cases, but very high for Science Journalists in Norway, Italy and Germany. This means that Science Journalists in those countries are very likely to engage users to comment on Facebook. When looking at engagement volume of the shares, however, we can see that they are generally high or zero, with Institutions/Organizations/Associations and Magazine/Publications displaying the highest median among the various countries.

Finally, we analyze the sentiment of all comments on Facebook posts made in 2019. As shown in Figure 3, we have generally the same distribution of sentiment across the countries. However, Estonian pages get the least negative comments and the most positive comments (as well as the fewest neutral comments) among the set, showing that interaction with Estonian science posts is generally favorable. German, UK and European pages seem to get the most negative comments, although comments for most countries are more likely to be neutral than anything else. French, Italian and German pages are all very likely to get neutral comments.

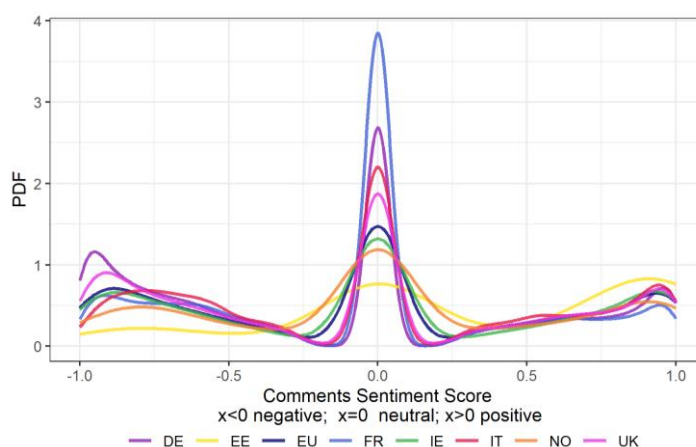


Figure 2 - Probability Density Function of Comment Sentiment on Facebook of each country for the period of 2019. Shows the distribution of the sentiment of the comments for each country, where negative values represent negative sentiment, positive values are positive sentiment and 0 represent neutral sentiment.

#### 4.4.2 YouTube

As with Facebook, science communication on YouTube increased over time since 2010. Differences in use can be noted when considering normalized posting frequency by country, with the UK publishing more than 25 videos per semester since the second semester of 2015. When considering the last three years, Germany and French pages also have a tendency to post frequently when compared to the rest of the countries. Estonian and Norwegian accounts publish videos considerably less frequently than the other countries, with Norwegian accounts increasing their production in the last year.

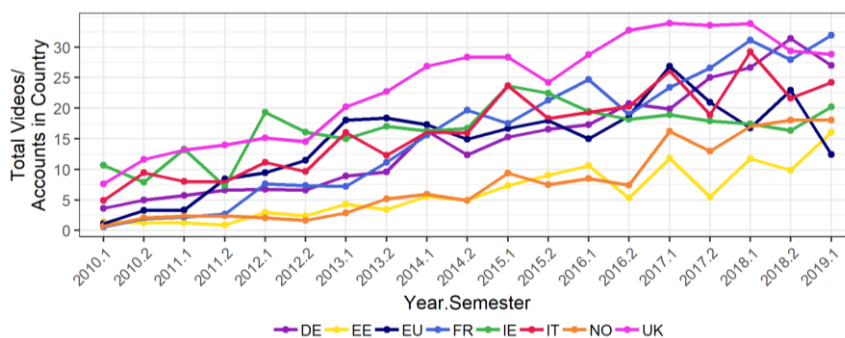


Figure 3 - Avg. Posting Frequency on YouTube Normalized per Country. Each semester shows the total number of videos published by each country in that time period, divided by the total number of YouTube accounts in that country.

As we did for Facebook, we use the Watson Natural Language API to obtain, where possible, three high-level concepts for each video published in 2019, based on the title and description. Once again, Norway and Estonia present lower number of concepts due to the lack of Estonian and Norwegian

language support by the Watson NLU software. For those countries, only content in supported languages is considered.

It is interesting to note that, while on Facebook the number of concepts by country were generally in the thousands, on YouTube the numbers are generally in the hundreds. This may indicate that

YouTube science communication has also increased. There are differences in frequency of posting content between countries. Similarly, German YouTube channels are more likely to reach large audiences than those from other countries.

Facebook has more variety of content than YouTube, while both platforms are quite diverse in terms of topics published. The reason for this might be due to different levels of expertise, time and difficulty required to produce content on the different platforms. It is after all much simpler to make a Facebook post than a YouTube video, so it is to be expected that more topics can be covered on Facebook in the same period of time. The extra work needed to publish on YouTube might also make the content more focused on specific topics that are known to get attention.

The majority of the concepts (99%) appear on less than 3.3% of the videos of each country; that is, a concept usually repeats itself in less than 3.3% of the videos published by each country. Among the concepts with higher frequency, Germany presents some notable cases with the concepts *welt*<sup>13</sup>, *prosieben*<sup>14</sup> and *aiman abdallah*<sup>15</sup> appearing in more than 25% of the videos (more than 300 videos out of 1194). The concepts that repeat themselves in more than 3.3% of videos can be found in Appendix B, as well as the wordcloud of the top 75 concepts of each country.

We now look at overall engagement and engagement volumes (corresponding charts are in Appendix B). Overall engagement (likes, dislikes, comments and views) shows significant differences based on the audience size of the different countries, particularly when considering active metrics (likes, dislikes, comments). German YouTube channels are considerably more likely to reach massive audiences, in contrast to the other countries. It is the most likely case of getting 10.000 likes, dislikes or comments (also the most likely to get 1M views). After Germany, the UK is the second most likely to reach large audiences when considering all four metrics. Then, depending on the metric considered, we can see that Italian channels are more likely to get more likes and comments and French channels are more likely to get more dislikes and views than channels from other countries. Channels from Ireland, Norway and Estonia have low levels of engagement compared to other countries, though this difference is less significant when looking at number of views.

<sup>13</sup> World in German. Could also refer to the newspaper Die Welt.

<sup>14</sup> Germany's second-largest privately owned television company. <https://www.prosieben.de/>

<sup>15</sup> Aiman Abdallah is a German television presenter for the German television show Galileo at ProSieben and former rugby national player.

Once again, while the possible reachable audience size by each country on YouTube differs significantly, the engagement volume is quite similar. Unlike with Facebook, however, some significant differences jump out. Norwegian videos are clearly the most engaging across all metrics and Estonian videos the second most engaging when it comes to comments. Irish and French videos have less probability of achieving high engagement volume across all metrics than those from other countries. This suggests that Norwegian and Estonian audiences interact more actively with science YouTube channels than French and Irish audiences.

After this engagement analysis we now focus on the different types of science communication sources and their engagement volume (for a detailed chart on this analysis please refer to Figure 21 in the Appendix). Some types of science communication sources are not very active on YouTube, such as Journalists and Scientists/Experts. The majority of countries and videos do not engage users to leave a dislike or a comment, save for the clear exception of German and Italian Science Journalists and German Scientists/Experts. Estonian channels from Industry/CEO, as well as European Magazines and Publications, are particularly engaging in terms of comments. Similar patterns emerge when considering the engagement volume of likes and views: when the YouTube channels exists for a particular source type, Estonia, Norway and the EU have generally high engagement volume.

Finally, we analyze the sentiment of comments on YouTube videos in 2019. We find that comments on Estonian videos are overwhelmingly positive, and are very unlikely to be negative. Comments on Irish, European and Norwegian videos are also more likely to be positive than negative. Comments on German videos are more likely to be negative compared to the other countries. However, comments on German videos are more likely to be neutral than anything else.

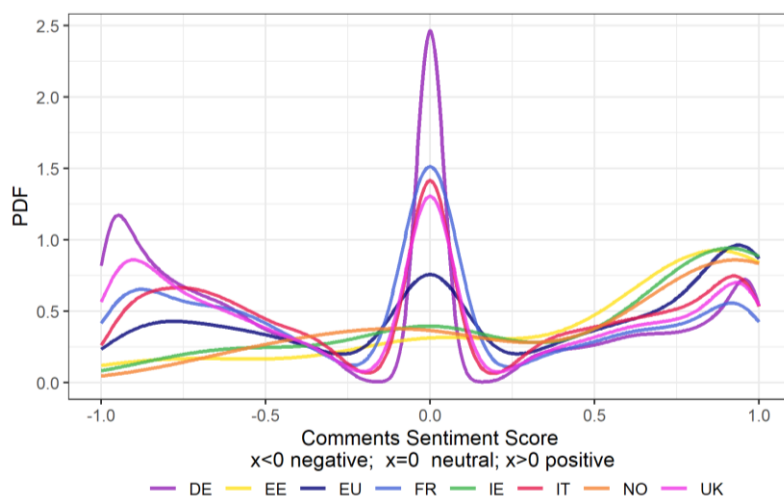


Figure 4 -Probability Density Function of Comment Sentiment on YouTube of each country for the period of 2019. Shows the distribution of the sentiment of the comments for each country, where negative values represent negative sentiment, positive values are positive sentiment and 0 represent neutral sentiment.

### 4.4.3 Twitter

Twitter posts refer to many more concepts than Facebook and YouTube.

In terms of engagement, there is a high likelihood of English language accounts getting more retweets. Scientists and other experts receive relatively high engagement volumes.

Science communication on Twitter maintains a quasi-constant frequency during the observed period, with some countries displaying more activity than others when considering the normalized posting frequency per country. European accounts are also quite active (with an average of 31 tweets per week) but are not as stable over time. The rest of the countries display stable activity, with British accounts the most active (a weekly average of 51), followed by France, Italy, Ireland and Germany. Norway and Estonia display the lowest posting frequency, with averages of 9 and 3 tweets per week,

respectively.

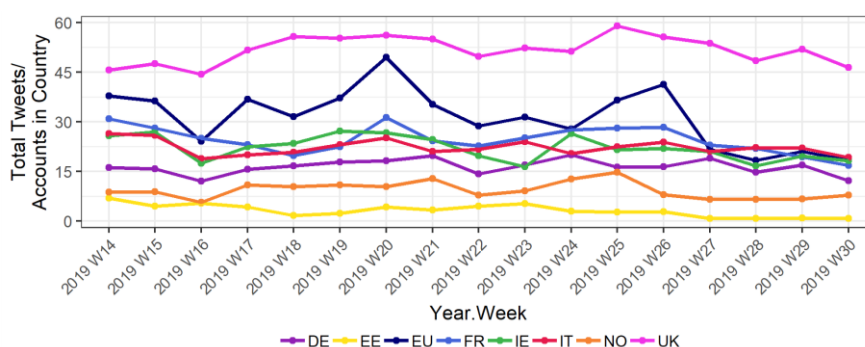


Figure 5 - Avg. Posting Frequency on Twitter Normalized per Country. Each week shows the total number of tweets published by each country in that time period, divided by the total number of Twitter accounts in that country.

As we did on Facebook and YouTube, we use the Watson Natural Language API to obtain, where possible, three high-level concepts for all the tweets in our dataset, all published during 2019. Once again, Norway and Estonia present lower number of concepts compared to the rest of the countries due to the lack of language support by the Watson NLU software. For those countries, only content in the supported language is considered.

Twitter presents many more concepts than Facebook and YouTube, a difference made more stark once we consider that the Twitter dataset covers a shorter time period than the datasets of the other platforms. The reason for this is probably due to the way in which the inherent difficulty of publishing content on a given platform affects the variety of topics covered. Publishing a tweet is easier than making a Facebook post or YouTube video, thus allowing users to write about a wider selection of topics in a short period of time.

The concepts that repeat themselves in more than 1% of the material can be found in Appendix B, as well as the wordcloud of the top 75 concepts of each country.

We now look at the overall engagement and engagement volume (corresponding charts in Appendix B). The overall engagement of all metrics (retweets and favorites) don't display significant differences across different countries. The most noticeable difference is the higher likelihood of British accounts getting between 100 and 1k retweets, and the limited maximum audience size, in terms of favorites, of Ireland (maximum 100) and Estonia (maximum 10) when compared to rest. As with Facebook, the distribution of engagement volume of all countries is quite similar. The only significant differences are Estonia's slightly higher and Europe's slightly lower engagement volume.

Once we know how 'appealing' science communication is in each country, we focus on different types of science communication sources (for a detailed chart on this analysis please refer to Figure 29 in the Appendix B).

We can see that the majority of the countries and accounts do not gain many favorites, and that the few that do have a high engagement volume (such as European and French scientists or Estonian Institutions). Tweets from Estonian Science Journalists are amongst the most engaging when considering the number of retweets. Industry accounts and accounts from Scientists/Experts are reasonably engaging when considering retweets.

When considering retweets, German accounts manage to engage with their followers very well for all source types, with the exception of the type Industry/CEO. Festivals do very well in terms of retweets (particularly for Germany, France and Ireland) and not so well in terms of favorites. The same can be said for Industry and Institutions (with the exception of German Industry).

Finally, it is interesting to note that Scientists and Experts have a higher median engagement volume than Science Journalists when considering retweets. This is particularly relevant if we consider that these source types do not display a similar behaviour on Facebook and are almost absent from our YouTube data. This may suggest that scientists are more likely to engage with their audience on Twitter than on Facebook, perhaps due to the inherent characteristics of Twitter, such as the text limit, the anonymity provided (compared to Facebook or YouTube), and the ease of use.

#### **4.4.4 The Case Studies**

First, we compare how the three different QUEST case studies - Vaccines, AI, and Climate Change - are managed across the three platforms. We can see that on Facebook and YouTube accounts are similarly active over time but present peaks of activity, indicating that a topic was particularly relevant at specific moments. For example, from 2015 to 2017 Climate Change produced considerably more content on Facebook than the other case studies. On Twitter, where the dataset covers a shorter period of time, we can see a more stable production frequency, with AI being considerably less active (an average of 11 tweets per week) than Vaccines and Climate Change (an average of 22 and 21 tweets per week respectively).



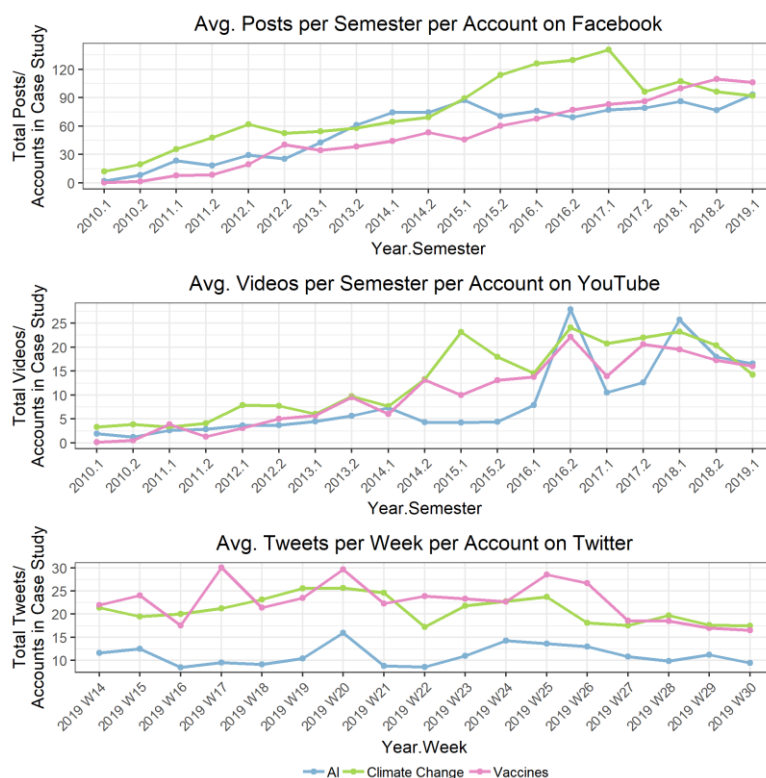


Figure 6 - Avg. Posting Frequency on each Platform per Case Study. Each semester/week shows the total number of posts/videos/tweets published by each case study in that time period, divided by the total number of accounts, in each platform, that focuses on that case study.

The overall engagement gives a general idea of the audience size of each case study topic on a given platform. For the visualization of this analysis, please refer to Appendix B.

On Facebook, Vaccination pages reach more people than the other two case studies when considering likes, comments and shares. Climate Change, however, is slightly more likely to get more than 31k likes or 1.7k comments than Vaccination. AI audience size on Facebook seems very limited, with posts unlikely to reach more than 1k likes or 100 comments or 100 shares.

On Twitter, the distribution of the number of retweets of each case study is very similar, more so than in Facebook. Here Climate Change is slightly more engaging than Vaccination. AI is once again the least engaging of the three, but the difference is lower than on Facebook. All three case studies present similar probabilities of reaching 10k retweets.

On YouTube, Climate Change is clearly the most engaging of the topics. It's the only case study topic likely to achieve more than 10k likes or 1k comments on a video. Vaccination and AI both reach fewer people than Climate Change, particularly when looking at active engagement metrics (like, dislike, comment). When we look at the passive engagement metric (number of views), the difference between case studies diminishes somewhat, with all three case studies having similar probabilities of videos with at least 100 views.

The engagement volume gives a general idea of how engaging the content is. For more details on this analysis please refer to Appendix B.

On Facebook we find that all three case studies are similarly engaging: users of all three case study topics interact with the content on similar levels. One slight variation can be seen on the probability of users commenting on Vaccine-related content, which is slightly higher than AI or Climate Change. Similar results can be seen on Twitter. While audience sizes on Twitter vary depending on the case study considered, the likelihood of user followers retweeting and favoring a tweet is very similar for all three cases.

YouTube, on the other hand, presents quite different levels of engagement volume, with AI engaging subscribers to like, comment and view the content more than the other two case studies. This is in stark contrast to the overall engagement analysis, where AI was the least likely to reach bigger audiences. This seems to indicate that while the audience of AI on YouTube is smaller, they are also more engaged. Climate Change, in contrast, can reach massive audiences but is less engaging to the subscribers.

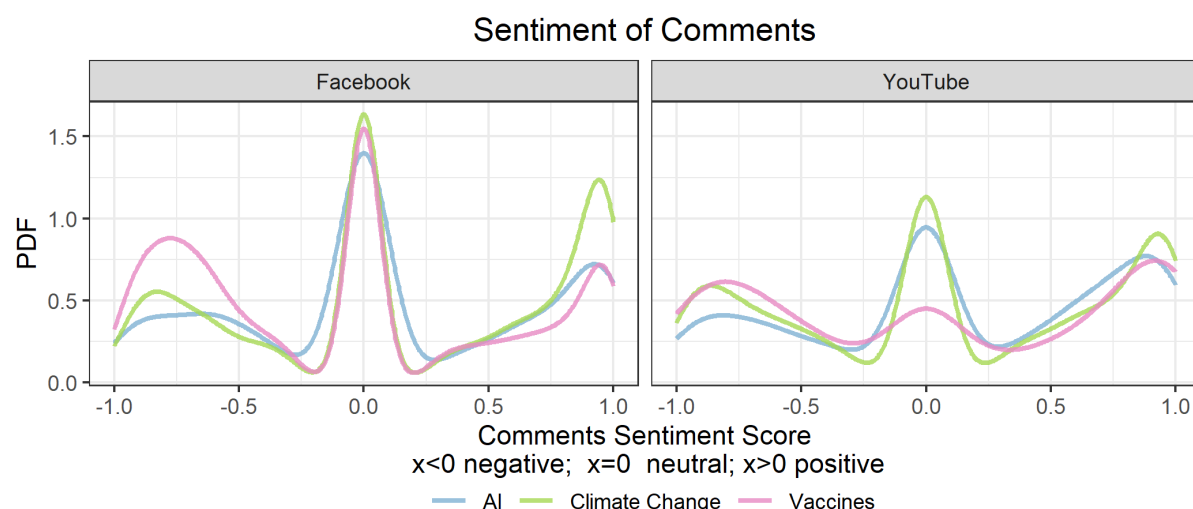


Figure 7 - Probability Density Function of Comment Sentiment on the comments of the Case Studies. Shows the distribution of the sentiment of the comments for each case study, where negative values represent negative sentiment, positive values are positive sentiment and 0 represent neutral sentiment.

Finally, we look at the sentiment of comments on Facebook and YouTube. We find that on Facebook the majority of the comments are neutral, regardless of the case study considered. When looking at non neutral comments, we find that comments on Vaccine pages on Facebook are more likely to be negative than positive, suggesting that vaccination on Facebook is a topic that is highly debated and very polarized. Comments on Climate Change and AI, on the other hand, are more likely to be positive than negative.



On YouTube, we find that comments on Vaccine pages are very polarized (more likely to be positive or negative than neutral), a situation that is not present in the other two case studies, highlighting that this topic is hotly debated and that climate change and AI seem to be less polarized.

## 4.5 CONCLUSION

In surveying the literature and contemporary practice of science communication on social media, we have made a number of arguments concerning the overall landscape of science on European social media. We summarise these below:

1. Over the years, science communication has increased on Facebook and YouTube as the platforms grew, indicating that there is an increasing use of social media in communicating science.
2. Some countries display a preference to publish content on a given social media platform (Italy and Facebook; the UK and Twitter; France and Germany and YouTube).
3. Twitter displays a greater variety of science content than Facebook and YouTube, and YouTube display considerably less variety than Facebook and Twitter. We speculate that this is due to the effort required to produce content on each platform.
4. The size of the audience reached on Facebook and YouTube by each country differ considerably between platforms. Popularity on one platform does not guarantee popularity in the other. On Facebook European pages are the most likely to go viral, while on YouTube it is German channels. For both platforms the UK is a close second.
5. When factoring in known audience size, engagement volume is similar across Facebook and Twitter, with YouTube displaying bigger differences between countries. On YouTube, videos from Norway are more likely to engage their audience than those from other countries.
6. When they have an account on a specific platform, Science Journalists, Scientists/Experts and Industry/CEO are all quite engaging - i.e., these types of sources receive high engagement from their audiences.
7. Scientists and Experts have a higher median engagement volume than Science Journalists on Twitter (for retweets). This is interesting when we consider that Scientists and Experts do not get similar levels of engagement on Facebook, and are almost entirely absent from our YouTube data. This suggests that scientists are more likely to engage with their audience on Twitter than on Facebook, perhaps due to the inherent characteristics of Twitter (e.g. it is easier to manage a Twitter account than a Facebook page, Twitter has text length limitations and allows users for more anonymity).
8. Climate Change and Vaccines reach more people than AI on all three platforms, showing a high interest on these topics.

9. While the AI audience is the smallest of the three on YouTube, AI content appears to be very engaging. Indeed, users interact with this kind of content more frequently than in the other case studies, indicating that the audience in this case is more involved in watching, liking, and commenting on AI videos.

# SECTION 5: SCIENCE COMMUNICATION IN MUSEUMS WITHIN EUROPE

## 5.1 INTRODUCTION

This section of the report investigates key issues in science communication in museums, providing an overview of the contemporary landscape of museum practice and scholarship into ‘quality’ in museum-based science communication across Europe. It is based on three activities. First, a literature review of the state of the art in science museum scholarship, with the aim of understanding key approaches and limits of current knowledge in this research. In this report, the literature reviewed focuses on studies that point the way towards best practice or ‘quality’ in how science communication is defined and delimited within the academic literature, particularly with regard to museum practice. Second, semi-structured interviews focusing on the contemporary landscape and key issues in ‘quality’ of science communication, were carried out with museum practitioners across Europe. Interviewee participants were identified from 15 partners involved with SySTEM 2020 (see [system2020.education](https://system2020.education)), a Horizon 2020 funded project. Third, we offer a case study of Science Galley Dublin to show the trajectory of museum practices and help illustrate broader trends in how creative approaches are emphasised by bridging science with art. This case was developed through observations of museum activities and the Science Gallery’s approach to encouraging creativity and facilitating critical thinking. Taken together through this review, we highlight museum scholarship and practice at the forefront of thought around ‘quality’ in science communication.

## 5.2 SCIENCE COMMUNICATION IN MUSEUMS: THE CONTEMPORARY LANDSCAPE AND KEY ISSUES

According to Rottenberg (2002) there have been a number of major trends impacting museums in the latter years of the 20th century. These trends include increasing prevalence of market-orientated ideology that has emphasised revenue generation and faster rate of new technologies introduced into consumer markets that compete for the attention of museum audiences. These challenges have faced museum practitioners more broadly as an apparent need to capture the attention of audiences through entertainment, rather than education. This competition for attention has concerned museum practitioners, such that becoming more “recreation-focused” may result in a loss of integrity as museums stray from their missions to educate (McPherson 2006). Indeed, McPherson (2006: 44) has

suggested that museums straying too far may become “arenas for pleasure rather than education”. These broader shifts in the consumer market have required museums to shift their focus, strategies, and roles as educational and learning institutions.

Such changes in the museum sector have included greater emphasis on engagement with their audiences. For example, Weil (1999) argued that museums should change their focus from being ‘about exhibits’ to being about the people they engage. Lang, Reeve & Woollard (2006) have argued that this shift would strengthen the role of museums in their responsiveness to society and the needs of their audiences. Increasingly, museum practitioners have needed to connect with policymakers and funding processes while brokering interactions between publics, researchers, and other stakeholders in education (Bandelli & Konijn 2015). In this regard, key challenges have been noted in the literature throughout the past decade for contemporary science museum practice (see: Kelly 2004; Chittenden 2011; Bandelli & Konijn 2013; Dawson 2014), including the following:

1. facilitating more public engagement opportunities to help shape science policies, research agendas, and governance structures;
2. engaging more broad and diverse publics;
3. competing with information and communication technologies (ICTs) among young people.

These broader trends and challenges, among others, have required museum practitioners to adapt by shifting their focus, strategies, and roles as educational and learning institutions to include a greater emphasis on how they engage with audiences.

The state of the art in science communication in museums centres around a number of key trends, building on a growing set of studies that point the way towards best practice or ‘quality’ (Patrick 2017; National Research Council 2009; Stocklmayer et al. 2010), specifically:

- socially inclusive science communication in museums;
- inquiry-based approaches to science communication in museums.

These trends require museum professions to adapt by shifting their focus, strategies, and roles as science communication institutions to include a greater emphasis on how they engage with audiences in their working contexts.

### **5.2.1 Socially inclusive science communication in museums**

Within the contemporary landscape of work to develop ‘quality’ science communication in museums, concerns about how to develop socially inclusive approaches have become a major theme in

contemporary practice and scholarship. Dawson (2014: 212) points to studies having shown that “most visitors to museums are from the dominant White ethnic majority, from upper and middle-class groups, educated to degree level, female, without a disability and based in urban areas” (also see DCMS 2011; Ipsos MORI 2001, 2006, 2014). Developments in museum practice and scholarship include an ever-increasing emphasis on engaging diverse audiences with science.

Dawson (2014) draws on Porter (1998) to clarify what is needed to develop greater social inclusion in museum-based science communication, which includes the following elements that affect potential visitors’ access and impacts. To really be socially inclusive, Dawson argues that all three of these elements must be addressed: 1) Infrastructure access needs, such as the cost and location of science museums, as well as other aspects such as staffing, marketing, and the way that programmes are developed. 2) Understanding how things work at the museum, including expected behaviour and the way that interpretation and exhibits work, 3) How accepting or welcoming practitioners are of the diverse range of potential audiences. Achieving these improvements has not been easy for science communication professionals in museums. There is clearly a problem of such institutions ‘preaching to the converted’ (Kennedy, Jensen & Verbeke 2018). Dawson’s (2014: 211) argument has gained ascendance, highlighting the ‘importance of recognising disadvantage and attempting to understand how disadvantage arises within’ museums’ science communication and audience development.

There is an urgent need to make science museums more socially inclusive, and for them to engage a wider range of audiences.

It is clear that most museums are communicating science disproportionately to economically privileged and ethnic majority audiences. And recent studies raise concerns that the ‘way science and science learning opportunities [are] constructed by [...] museum[s] positioned science as a Eurocentric, male and privileged pursuit’ (Dawson et al. 2019: 6). Similarly, Feinstein (2017) argues that attracting more diverse audiences to science museums may be insufficient. This is because museums’ existing science communication approaches would not resonate with many of the categories of non-visitors. This line of research suggests the need for fundamental change in museum-based science communication to achieve true, socially inclusive ‘quality’.

Supporting this perspective on the need to enhance social inclusion in museum-based science communication is research based on the work of French sociologist Pierre Bourdieu. Bourdieu’s theory of practice focuses on how social inequality is reinforced through institutions, including museums (Bourdieu 1986). Application of his work in recent years has been used to highlight the problem of socially exclusive patterns in museums’ science communication approaches. Most notably, Archer et al. (2015) have introduced the concept of ‘science capital’, which has been criticised as needing to more fully address the “systemic pattern throughout society reproducing deeply unequal, unjust and

exclusionary social relations, even when financial barriers to cultural participation appear to have been addressed” (Jensen & Wright 2015: 1144) by museum-based science communication.

### 5.2.2 Inquiry-based science communication in museums

Inquiry-based approaches to science communication have gained ascendancy within the contemporary landscape in recent years in both museum research and practice. This term refers to how audiences can gain a greater appreciation of scientific ideas through developing hypotheses and testing them for themselves through observations and experiments (Pedaste et al. 2012). By observing, hypothesizing, collecting data, discussing findings and drawing conclusions, museum participants can gain science-related skills and knowledge that resonates because the engagement develops from the spontaneous curiosity of audiences and enables them to answer their own questions (Hohenstein & Moussouri 2018). This approach can also boost attention and learning by increasing the relevance of the scientific content for audiences (Hidi & Renninger 2006). It fits well with the less structured science communication experiences that take place in museums and museums’ focus on real objects (Braund & Reiss 2006) and authenticity (Pekarik et al. 1999). In addition, visitors gain new insights while involved in informal conversations and facilitated sessions with real objects as a spark or touchpoint (Bunce 2016; Van Gerven et al. 2018), as well as through direct reading or viewing interpretation (Fraser, Clayton, Fraser & Saunders 2008; Moss, Jensen & Gusset 2017; Falk & Dierking 2013). Within museum-based science communication, a range of formats can be used to develop effective engagement following an inquiry-based approach, including facilitating interactions with practising scientists and active scientific research (e.g. Jensen & Buckley 2014).

In inquiry-based approaches, museum participants can gain science-related skills and knowledge that develop from their spontaneous curiosity and that enables them to answer their own questions.

This approach has especially been welcomed within the museum-based science communication landscape, particularly where there are links to ‘maker’ or ‘tinkering’ activities. In such activities, participants often gain a new perspective on a scientific idea through ‘doing’ (Vossoughi & Bevan 2014). They have a challenge that they seek to address in a participant-driven way by drawing upon available equipment and resources, and this can be an effective approach with the right structure and scaffolding (Gutwill et al. 2015).

The key trends in the contemporary research and practice landscape discussed above point to a number of directions for developing quality in science communication. Increasing the relevance and culturally relevant meaning of museum-based science communication is clearly essential (Simon 2016). In the following sections, we turn to a study of different museum professionals views about ‘quality’ science

communication and how practitioners in contemporary working contexts view the challenge of effectively developing their audience engagement.

## 5.3 KEY THEMES IN STAKEHOLDER PERSPECTIVES ON THE EUROPEAN SCIENCE MUSEUMS LANDSCAPE

Participants emphasised ‘quality’ in their work context around the importance of dialogic approaches. Such dialogue is seen as an alternative to ‘formal’ schooling and as offering better connections between public audiences and researchers.

This section describes key themes from interviews with participants from European museums and science centres in order to clarify their descriptions of the contemporary landscape of science communication.

### 5.3.1 Introduction

Definitions of quality in science communication have been much debated over the years. These interviews were conducted with the purpose of elucidating perspectives about science communication in the working contexts of museums and science centres. This section adds to the existing debate on this topic by presenting research findings from exploring the landscape of European science communication in informal learning environments.

This contemporary landscape and key issues in ‘quality’ of science communication were explored through interviews with museum practitioners throughout Europe. This research conducted regards the characteristics important for ensuring ‘quality’ in science communication including interaction, tools or methods and scientific accuracy.

In addition, the research highlights key arguments about what is and should define quality in science communication as we move into the future. The literature reviewed focuses on studies that point the way towards best practice or ‘quality’, particularly with regard to socially inclusive and inquiry-based approaches in museums as well as the role of evaluation and evidence in defining best practice.

### 5.3.2 Indicators for Quality

There was an indication of consensus from interview participants when asked what ‘quality’ in science communication looks like in their working context. From these perspectives, indicators of ‘good’ quality in science communication can be summarised into three primary themes (Table 1).



Table 2. Characteristics of quality indicators in museum-based science communication

<b>1. Collaborative</b>	Using communication methods that are collaborative, multidisciplinary and pulls in different perspectives in the community.
<b>2. Engaging</b>	Making content interactive and exciting to stimulate further engagement and discussion.
<b>3. Relevance</b>	Making content relevant for specific audiences and their daily lives to ensure interest, make engagement more likely and provide opportunities for transference of knowledge.

These themes are described below according to the perspectives provided by interview participants.

Characteristics of this first theme include the importance of collaborative interactions and two-way dialogue as an indicator of ‘good’ quality in science communication. Participants expressed that methods involving a two-way exchange between researchers or facilitators and public audiences are effective for encouraging audiences who “are not experts” to be actively involved in scientific topics:

We don’t want to just deliver science facts. That’s not what being science scholar is about. It’s much more about encouraging critical discussion around scientific topics and bringing people together from diverse backgrounds to do that. We don’t want to teach or educate people about science, we just want to open up conversations. (Science Gallery)

Alternatively, when discussing ‘poor’ quality, participants almost unanimously referred to science communication methods which feel top-down or one-way from scientists, researchers or academics to audiences. Simply providing information was not seen as inspirational, especially when making a programme for the general public or working more specifically with families, adults and children.

This also reflected consideration that the use of ‘scientific language’ that can make concepts difficult for people to understand. For one participant, this revolved around ‘learning equality’ in the sense that audiences will have differing levels of knowledge prior to their arrival to a science museum. This participant wanted to better understand how to utilise different forms of knowledge exchange to invigorate collaborative learning experiences.

Some participants likened undesirable outcomes with science communication to traditional education or school settings, with few opportunities for discussion, interaction or participatory elements:



When you want teachers to teach science or different subjects, they would lecture what would be exceptionally boring for children. Maybe that's fine. Just comes to my mind as negative. I would not say 'quality'. (Science Museum)

Participants associated with 'top-down' or 'formal' learning environments, with a desire to move away from lecturing or 'delivering science facts' and data. Participants suggested their institution was situated within an educational climate that did not allow children to express creativity nor provide opportunities for teachers to see children in different contexts. For these participants, this indicated barriers to engaging children in ways which were aligned with 'strict frameworks' for education.

This highlights critical tensions between needing to keep engagement high and an institutions' perceived responsibilities to educate an audience. This was implicitly characterised by participants' assumptions about problematic science communication and yet the tendency for most participants was to avoid responsibility for scientific education.

The second theme involves making content interactive and exciting to stimulate further engagement and discussion. Various methods and tools are seen as helping to facilitate the exchange of ideas between audiences and researchers, such as games and maker spaces to excite children and families about science:

Activeness is the most powerful quality of when someone wants to communicate science to others. You have to use the methods and tools to ensure that there is interactivity between people that you want to communicate science. (Science Centre & Technology Museum)

This aspect of science communication regards perceived needs for communicators' to share their 'love for science' while being lively, fun or exciting:

This love for science from the people that are working to communicate it goes then to the people that are receiving these experiences from them. (Science Centre & Technology Museum)

Participants highlight the importance of ensuring that communicators are engaging when delivering content to an audience. In this regard, 'successful' interactions are seen as a result of having stimulated interest and engagement in an audience:

Our goal is mainly to create exciting content for visitors, for the younger and to put them into a context in which makes them excited about a certain topic. (Science Museum)

Participants suggested that interest and excitement connect to a 'state of happiness' or 'flow' when audiences engage with scientific topics. Participants considered their ability to design science

communication methods and content around the needs and interests of those perceived as commonly visiting.

The third theme involves participants' efforts to create connections with audiences by making science topics relevant to their daily lives. This was important to make connections between 'public' audiences (i.e., kids, people, citizens or public), and 'science' researchers (i.e., scientists) around scientific topics or themes, and industry. Such connections with general audiences are seen to involve efforts to raise awareness of science:

Mostly what we do is actually a connection between science and industry and actually trying to raise awareness of the general public of the importance of science in general. (Science Centre)

Participants mentioned the need to engage with stakeholders in formal education, as well as private and public institutions, such as businesses and policymakers, which may extend beyond audiences in the general public to include bodies that also influence broader publics. Other participants shared this interest for a greater understanding of collaborations between science communicators from different fields. This indicates a potential for classification systems or indexes that describe effective approaches for different science topics.

### **5.3.3 Achieving Quality**

Once the characteristics of good and poor quality science communication had been discussed, participants were asked about the strengths of their respective institutions in achieving quality. As such, responses covered various practical concerns in the process of science communication, including locating funding sources, understanding communication styles, and building collaborative approaches with other institutions. Responses revolved around components of science communication, such as an understanding of their audiences, effective methods or tools and ensuring scientific accuracy. These components are reflected in overarching characteristics for achieving quality in science communication (see Table 2).

Table 3. Characteristics for achieving quality in museum-based science communication

1. <b>Social Inclusion</b>	Understanding how to reach diverse audiences, broaden the range of activities and topics of interest who may be underprivileged or overlooked.
2. <b>Inquiry-based approaches</b>	Understanding how to improve content interactions, excitement and relevance for specific audiences to ensure the effectiveness of various methods.

These characteristics are seen by participants as precursors that allow science communicators to provoke questions and engagement through discussion with an audience. Most participants suggested that this results in a richer learning experience for their audiences, but these claims must be accurately evaluated to identify the most effective science communication practices and the factors that make them effective.

### 5.3.3.1 Social Inclusion

In considering 'good' quality in science communication, participants suggest that communication methods should allow different voices to be heard from within a community. Participants noted their perspective that bringing people together with different perspectives can help audiences approach scientific themes or topics from new lenses. Participants reflected on elements of quality they had previously mentioned, including tailoring content to be relevant to certain audiences, encouraging interactivity, and showcasing a variety of perspectives.

There is an apparent desire to provide safe spaces for audiences to contribute their own ideas and opinions to discussions about science topics.

With this consideration for audiences, there was an apparent desire among interview participants to provide safe spaces for audiences to contribute their own ideas and opinions to discussions about science topics:

A good quality event would be one where different perspectives are offered and it's a safe space, where everybody feels safe to offer their perspectives and their opinions are valued. (Science Gallery)

This mindset towards collaboration extends further for participants to ensure that content is multidisciplinary, including diverse backgrounds and a range of perspectives:

I'm always trying to get as diverse voices involved as possible contributing to events. That's really important for attracting a diverse audience. (Science Gallery)

Participants indicated their willingness to change science communication methods and content or develop spaces and activities based on the community of perceived visitors:

When we realise there are differences between genders, then we have to adjust our communication techniques so that they can include all this diversity. (Science Centre & Technology Museum)

Participants acknowledged that efforts needed to be made to adjust communication techniques to reach diverse audiences. This demonstrated an interest to improve the reach of science communication but having plans to achieve quality standards was important for institutions to focus their resources and efforts. Such plans could be manifested through project-related efforts to promote that more girls should choose scientific careers. There are evident differences in how participants thought achieving this goal was possible. This understanding is central to efforts to adapt language and content to specific audiences. However, practical challenges were expressed for audience engagement. Upon reflection, most needed to improve with respect to delivering good quality science communication, responses mainly revolved around the difficulty of reaching different audience types, and diversifying activities to keep up with current trends.

This is still new and difficult for us. I wouldn't say we have found the right approach to reach as many diverse people as we would like to. I'd say that we still have work to do in that direction. (Science Museum)

When quality standards were oriented towards raising and encouraging open conversations there was greater willingness to ensure that activities included people from diverse backgrounds. For example, further social and cultural barriers were reported, such as difficulty reaching children whose parents may not be engaged or able to support their child's learning, thereby leading to unequal access to science communication opportunities. Such issues may be compounded by less funding for outreach and a lack of training or knowledge in best practices for how to communicate effectively to diverse audiences.

### 5.3.3.2 Evaluation and Inquiry-based Approaches

When interview participants were asked how they know what good science communication is in their working context, responses revolved around efforts to improve practices and understand audiences. Evaluation often took place with questionnaires or interviews, while others used observations and unstructured or intuitive approaches. When participants mentioned specific information or metrics they wanted from evaluation, data related to a number of visitors they were reaching, through which communication channels, and whether they were reaching target audiences. Questionnaires were seen to gain an insight into how audiences learned about the activity and how positively activities/visits were perceived based on their experience or self-reported satisfaction. Most participants recognised the possibility that these methods could contribute to a deeper understanding of their audiences, yet others expressed a lack of confidence in how to effectively use inquiry-based approaches. Participants further expressed concerns about results as presenting only a ‘bubble’ of visitors that were not representative of the wider community. Many participants reported recognition of key challenges that must be overcome when evaluating such projects.

Participants recognised the possibility that these methods could contribute to a deeper understanding of their audiences, yet expressed a lack of confidence in how to effectively use inquiry-based approaches.

To gain an understanding of communication, participants noted that they observed interactions between the guides and visitors to see how communications were conducted:

We do observation, but for us, mainly what we do for the observation is to observe our guides to see if the way they communicate is the way you would like them to communicate. So when we do observation, we focus on the interaction between our guides and the visitors. (Science Museum)

Some participants expressed views that quantitative data collection was not meaningful for evaluation, but rather that meaningful evaluation was best gained through qualitative data. Other than on observations, interviews and focus groups were suggested as preferred inquiry methods:

We do, from time to time, some focus groups and we try to understand from them, but we know that it's also very limited. These discussions cannot really lead us to a very deep understanding. (Science Museum)

As this deeper understanding is an objective of interviews and focus groups, this indicates an issue with capacity for research methodology to explore audience experiences, as well as a lack of internal knowledge about how to evaluate effectively. Compounding this issue, participants note that many institutions do not use ‘classical’ evaluation methods:

We don't do classical evaluation but we look every week to see what happens and how we do next week.  
(Science Centre)

Others suggested the use of intuition:

We do not do real research in a scientific way, but more in an intuitive way. (Science Museum)

These situations seem to arise from not knowing how to effectively evaluate. This was particularly relevant to evaluating the long-term impact of visits to science institutions:

We can't know what we're doing is actually having any impact unless we evaluate it properly. (Science Gallery)

While many participants reported recognition that impact needed to be evaluated properly, some participants held the opinion that they could not evaluate the impact of science communication:

We can't evaluate impact but we would like to see that activities are not ending by being in interaction in our museum. We want to see a follow-up afterwards. (Science Museum)

One possible explanation from participants was not having enough funding, seen as a common barrier that prevented the development of evaluation tools and training. Whereas, external evaluators were found in institutions that had available funds and needed more detailed information that they routinely collected. Participants noted that external evaluators were used as an 'extra support' for those with a normal role to conduct an evaluation or work collaboratively with others inside the institution. This reflects a number of key challenges reported by participants in how to find a balance between these other priorities in science communication, such as engagement, education and evaluation.

## **5.4 CASE STUDY: SCIENCE GALLERY DUBLIN**

This section explores key issues with science communication that are reflected both in the contemporary landscape across Europe and in the case study provided here, that of Science Gallery Dublin.

### 5.4.1 Background

Trinity College Dublin (TCD) is home to the living experiment that is Science Gallery Dublin (SGD). Science Gallery began as a way to deliver unique and transdisciplinary exhibitions, events, and educational programmes with the potential to engage young, inquiring minds in connective, participative, and surprising ways. The vision was of social space to develop ideas, imagine the future, and realise dreams. Science Gallery has welcomed more than 2.5 million visitors since it first opened in 2008, and has spawned the sister organisation, Science Gallery International, with the mission of establishing similar venues around the world.

The trajectory of practice within Science Gallery Dublin helps illustrate broader trends in museums that emphasise creative approaches to diversify audiences and funding alternatives.

From the outset, Science Gallery sought to build a creative bridge between art and science, fostering scientific literacy and encouraging public engagement with STEM subjects. The unique situation in Ireland relative to the emerging STEM industries of the early 2000s provided a platform that would allow Science Gallery to take a position central to Ireland's scientific, cultural, and art scenes (Brunswick 2017). Brunswick specifically identifies four factors key to the Science Gallery's inception:

- A group of university scientists motivated to communicate with the public about contemporary science.
- An increase in government investment in science and in science communication.
- A university-wide policy in TCD that made public engagement a component of all new building projects.
- A project leader with a well-defined concept, and the support and freedom to pursue an experimental and unproven model (p. 160).

The pervading image of science as a narrowly focused, socially isolated vocation for the initiated was considered by some to be a deterrent to talented young people entering the field (Gorman 2008). Combining science and technology with art and design could open up the discipline to various publics, and stoke interest in and passion for STEAM and related subjects, where 'A' represents the arts in alignment with the traditional fields of science, technology, engineering, and mathematics.

### 5.4.2 Mission

Science Gallery stands at the forefront of interfacing cutting-edge research with art, design, and social concerns, allowing members of the public to interact with university-level research in an informal science learning environment (ISLE). Science Gallery inspires, and in turn, is inspired by global communities. By actively engaging with and involving students, staff, and researchers from universities and cities around the world in its activities, Science Gallery aims to create interactions that feel fluid and natural, much like a porous membrane between the university and its locality. Practitioners at Science Gallery aim to operate under the core missions of 'igniting curiosity' and 'nurturing new ideas' that integrate art and science. Fostering a culture of trust and transparency between scientists and the public continues as a core value at the heart of SGD practices, made possible by the unique methods for approaching and interacting with visitors from the community. The 'Do it with Others' model of public engagement can be seen at work in the museum as practitioners seek to incorporate the views of visitors, particularly young people, into the curation process at exhibitions. There is a long-standing effort to understand the strength from collective and collaborative emphasis on interactions, as key to practices that overcome obstacles to learning and are essential values to this approach. While moving away from a 'one size fits all' model of science communication, Science Gallery aims to operate on a basis that more perspectives incorporated into the consideration of societal challenges can broaden the scope for social inclusion, progress and innovation.

### 5.4.3 Target Audiences

All of the exhibits are designed specifically to engage and challenge teenagers and young adults between 15-25 years old, and seek to provide a space for younger generations to pursue creative ideas that explore and push the boundaries of, and between, art and science. By examining the similarities in practice common to both museums of art and of science, Science Gallery is exploring ways to broaden youth participation in informal learning. The Gallery Network particularly engages those 15 to 25-year-olds who are passionate about art, science, design, technology, and innovation, and who are keen to contribute to the Gallery's planning and projects; ensuring that young voices are heard. Science Gallery is dedicated to having young and curious people at the centre of the curation process.

### 5.4.4 Exhibitions

SGD runs an ever-changing programme of exhibitions and events fuelled by the expertise of scientists, researchers, students, artists, designers, inventors, creative thinkers, and entrepreneurs. Past exhibitions were designed under such themes as 'Perfection', 'Open Labs', 'Humans Need Not Apply',



‘Life at the Edges’, and ‘Fake’. While the model for programme development is centred around public engagement, the process begins with the Leonardo Group, a steering group of fifty leading experts in Ireland. The members come from varying backgrounds and have diverse skill sets spanning architecture, design, and science. Once the overarching exhibition themes are decided, ideas are generated through open calls, school talks, and canvassing in the existing Science Gallery community and beyond. The gallery is a testament to how cultural organizations can meaningfully engage communities in the creative process, allowing participants to have their voices heard and the merit of their work and contributions recognised.

### 5.4.5 Events

The values and life experiences of the staff are crucial to how the gallery is run and how it continues to be shaped. Michael John Gorman and Lynn Scarff were the key figures in the initial development and establishment of Science Gallery. Together, they shaped it into an innovative project that is also a social space which is open, accessible, free to enter and to participate in. It is the Science Gallery team, from managers to mediators, who have the greatest impact in steering the development of the Gallery and all of its varied activities. The team look closely at the role and reactions of the public, and investigate new ways to conceptualise and produce intriguing aesthetics that provoke reactions and conversations. This aligns with Euler’s (2017) emphasis on the crucial importance of interlinking learning experiences in science museums with more formal educational settings.

### 5.4.6 Education

Hall et al. (2012) show how rapidly traditional teaching methods are evolving. Therefore, the remodelling of conventional approaches to public engagement is necessary, particularly to facilitate critical thinking and expert leadership. As outlined above, Science Gallery has always integrated participant views and ideas from exhibit conception to implementation; the end-user experience is important, but public participation in the creative process is essential. This is in line with the recommendation of the National Research Council (2015), wherein the value of learning outside of traditional classrooms has been proven to enhance interest in and understanding of STEM subjects.

Embracing the STEM to STEAM movement is at the core of educational initiatives taking place at Science Gallery (Bevan et al. 2017), where issues that are important to young people, including topical subjects such as climate change, vaccinations, and artificial intelligence, can be explored in ways that are impactful and engaging to this audience. Science Gallery runs a number of programmes to ensure that under-represented audiences have an opportunity to interact with exhibition themes. For example,

each year a group of transition year students (approx. 15-17 years of age) are invited to take part in week-long courses held at Science Gallery to experience an innovative and collaborative learning environment, where they can discuss the future they would like to shape and live in.

### **5.4.7 Mediators**

Each exhibition at the Science Gallery is staffed by a team of students and recent graduates who share a passion for engagement, learning, and creativity, who work in the gallery as science communicators. These ‘mediators’ are the public face of the gallery and are tasked with explaining concepts and stimulating conversations about art and science with visitors. The mediator programme not only enhances the visitor experience, but is also structured as to be beneficial to the staff themselves, building confidence and promoting civic engagement, interest in social justice, and empathy (Enros & Bandelli 2018).

### **5.4.8 Network**

The rise of SGD is easy to chart — what initially began as a flagship engagement project connected to TCD quickly became the pioneering gallery for the Global Science Gallery Network, a network of eight Science Gallery locations, developed in partnership with leading universities in urban centres across the globe. Each specific Science Gallery now creates exhibitions and programmes generated from the local creative and scientific community, which can be shared through the global network and beyond, increasing public understanding and access to high quality science-art public engagement.

To celebrate this growing community, SGD held the first full-day ‘Youth Symposium’ in 2018. This event was subsequently hosted by the London Science Gallery in 2019. The Youth Symposia are an opportunity to engage and connect with young people who possess a passion for change and are eager to share their ideas with the world. The Science Gallery Network is a collaborative organisation that empowers young people to go beyond discussing global challenges to being involved in solutions that drive progress and implement change. The symposia are an important vehicle for youth mobility, intercultural exchange, and knowledge sharing; offering participants a chance to experience how using an art and science frameworks to reaffirm the importance of accountability, responsibility, and how collaboration can aid the youth of today in standing up to the challenges they may face.

### 5.4.9 Critical Synthesis

Although the mediated approach to science communication in the Science Gallery is focused on the idea of dialogue and participation, this is not always possible in practice. Often the default mode of communication by the Science Gallery mediator team reverts to a one-way mode of communication similar to the traditional "explainer" approach favoured in science museums (Diamond et al. 1987). The one-way or "deficit" model of communication is considered outdated in the field of modern science communication but it might still have its place when there are few other viable options (Trench 2008). The audience that Science Gallery attracts is not as inclusive and diverse as it needs to be as it does not reflect the diversity of the local community in which it is based. This is not unexpected given the challenges in the field as described by Dawson (2014). While aspects of the Science Gallery expansion to become a Global Network have been easy to measure, the impact that the exhibitions, events, and education programmes have had on people has not yet been explored or systematically evaluated. This is in keeping with the general and long-standing lack of critical evaluation across the field of science museums evident in the literature (Beetlestone 1998) and key challenges presented in this report by interview participants (see Section 5.3.4).

## 5.5 CONCLUSION

This section has explored the contemporary landscape of science communication in museums across Europe, with a special focus on 'quality'. The emphasis has been on how this is characterised by scholarship in the field and museum professionals. We review the state-of-the-art in science communication from academic literature and exploring the context for museum practice we build on prior arguments that science communication is a fragmented and changing field.

Additionally, we extend this argument to point the way towards best practice or 'quality' from a growing set of studies around a number of key trends in science communication at museums and science centres. These trends have required museum professionals to adapt their practices towards socially inclusive and inquiry-based approaches to science communication. Furthermore, we provide evidence from interview participants of such shifts in focus, strategies, and roles as science communication institutions continue to include a greater emphasis on how they engage and interact with audiences in their working contexts. Findings show museum sector professionals' views about various indicators of 'good' quality are identified as collaborative, engaging, and relevant to public audiences, while 'poor' quality can be seen as the opposite of these indicators. However, while these indicators are discernible in museum professionals' views, there exists substantial difficulty in actually developing experiences for their audiences that are defined by these characteristics. Key challenges revolve around how to ensure social inclusion, including reaching different audience types and

diversifying activities to keep up with current trends. Other key challenges include developing appropriate implementation methods, ensuring scientific accuracy in their communication, as well as overcoming internal capacity limitations in training, planning and evaluating activities and interactions. Participants also recognised challenges and limitations in capacity to conduct a high-quality evaluation, sometimes expressing the view that the impact of their work could not be evaluated.

Finally, we offer a case study to show the trajectory of museum practices within Science Gallery Dublin and help illustrate these broader trends in how creative approaches are emphasised to stay relevant in the minds of diverse audiences by bridging science with art, encouraging creativity and facilitating critical thinking. Taken together through this review, we highlight museum scholarship and practice at the forefront of thought around ‘quality’ in science communication.

## SECTION 6: CONCLUSIONS

This report summarises the work carried out within Work Package 1 of the QUEST project. It draws together findings from four tasks, each of which focused on a different aspect of the contemporary European landscape of science communication: research, science journalism, social media, and museums. In doing so it has used a number of different methods – from analysing big data to literature reviews and qualitative interviews – and focused on diverse topic areas.

What this text offers is thus a series of snapshots into science communication as it is currently practised and discussed across Europe. These snapshots are not comprehensive, but they do provide important data on the key issues that are at stake and the central challenges facing (different aspects of) science communication. Here we briefly re-state key findings from the report as a whole and discuss central implications of these.

### 6.1 KEY FINDINGS

We can summarise key findings from each of the areas of science communication that the report focuses on as follows:

#### 6.1.1 The landscape of European science communication scholarship

- From academic literature, we find that science communication is frequently framed as a means to bridge gaps between science and wider society. Scholarship has been oriented towards distinctions between ‘one way’ and two- or multi-way communication.
- There is little consensus regarding the overall landscape of European science communication scholarship. The field is fragmented through gaps between research and practice; between national contexts; and disciplinary and ideological positions.
- While there were few clear patterns within stakeholder interviews there were a number of repeated concerns: the need for better understanding of social media; a sense that the field should move away from normativity and/or instrumentalism; and a concern about science communication as an uncritical promotion.

In sum, we might say that while European science communication is a fractured, multi-disciplinary domain of scholarship, some central concepts hold sway: specifically, the notion that dialogic and critical forms of science communication are particularly valuable.

### **6.1.2 The landscape of European science journalism**

- Science journalists comprise a relatively homogeneous community, with clear patterns in their practices and views. Many worked across multiple platforms and were involved in writing and producing different kinds of content.
- There were different views on the role of science journalism. While scientific literacy was viewed by some as important, many felt that science journalists also had a critical or investigative role, beyond acting as a mediator between science and society.
- Funding - in the context of shifting media landscapes - was a central concern. Other challenges included trust (with sources and audiences), and the rise of fake news.

In sum, we might say that European science journalism faces central challenges with regard to funding and the structural changes to the profession that this is entailing - challenges that call for reflection about journalism's traditional role as offering a critical view on science.

### **6.1.3 The landscape of science on social media in Europe**

- Since 2010, science communication has increased on Facebook and YouTube (corresponding with a growth in these platforms overall).
- Some countries display a preference to publish content on a given social media platform: Italy and Facebook; the UK and Twitter; France and Germany and YouTube.
- Twitter displays more variety of science content than Facebook and YouTube, and YouTube display considerably less variety than Facebook and Twitter. We speculate that this is due to the effort required to produce content on each platform.
- When factoring in known audience size, engagement volume is pretty similar on Facebook and Twitter, with YouTube displaying bigger differences across countries.
- When they have an account on a specific platform, Science Journalists, Scientists/Experts and Industry/CEO are all quite engaging - i.e., these types of actors receive high engagement from their audiences.

- Scientists and Experts have a higher median engagement volume than Science Journalists on Twitter (for retweets).

In sum, we can say that there are clear differences between social media platforms in terms of how science is presented and engaged with, as well as between what forms of engagement are most common in different national contexts. Key science communication actors - such as journalists, scientists, and experts - tend to be successful in promoting engagement with their content.

#### **6.1.4 The landscape of European science museums**

- Both literature and museums practice suggests that there is an urgent need to make science museums more socially inclusive, and for them to engage a wider range of audiences.
- Inquiry-based approaches have risen to the fore in contemporary museums practice. These empower audiences to follow their own curiosity and to be active in the museums' experience.
- Similarly, museum stakeholders emphasise the value of dialogic approaches within museums. While scientific accuracy is important as a baseline for quality, an exchange of ideas between researchers and public audiences is viewed as most productive for inspiring and empowering visitors.

In sum, we might say that European science museums are currently seeking to diversify their audiences and to employ more creative approaches to engagement. Central to this is a commitment to dialogue.

## **6.2 IMPLICATIONS**

Across these disparate domains, we can discern some cross-cutting themes and challenges. We discuss these below.

### **6.2.1 Critical and dialogic approaches are key**

If there is an overall trend driving contemporary science communication based on these data, it is one that mitigates against simplistic notions of communication as information transfer and towards good quality science communication as dialogic, critical, and participatory. While science communication scholarship is fragmented, one of the rather few widely referenced central concepts is a move from a 'deficit model' of public audiences towards models of engagement and multi-way communication (see

sections 2.2; 2.3.3). We also find such models propounded within museums practice (section 5.3). Similarly, journalists emphasise the need to go beyond science journalism as translation or promotion to incorporate critical views, investigate the scientific practice, or challenge ‘bad science’ (section 3.3.1). In this view quality with regard to science communication goes beyond being scientifically accurate or balanced, and instead involves openness to diverse voices and the promotion of societal discussion about science.

### 6.2.2 Format matters

This report also suggests that there are central differences between science communication practice in different contexts. Section 4 has comprehensively demonstrated that social media platforms are used in different ways, and that there are interesting national differences in which platforms are preferred. Perhaps most strikingly, we can observe that there are many more science-based topics discussed on Twitter than on YouTube (in particular), and that scientists and other experts are particularly active (and gain high engagement levels) on Twitter (sections 4.4.2; 4.5). These different platforms seem to offer different affordances for content production, with YouTube requiring significantly more time, effort, and (potentially) resources. Similarly, we can see differences between the issues currently at stake in the worlds of science journalism and science museums, and the key challenges these forms of practice are facing. If we are concerned with good quality science communication, then, it seems likely that we will have to pay attention to the *format* of that science communication: best practice for Twitter may not be the same as for Facebook, while the norms of good science journalism may not be the same as for those in the museum world.

### 6.2.3 A changing landscape

A further common theme is a sense of science communication being in transition. Within scholarship, we have seen that interviewees represented the field - and therefore key sites and centres of knowledge production - as being in flux (section 2.3.1). This sense of a changing landscape is particularly acute within domains of practice: science in social media is on the rise (sections 4.4.1; 4.4.2); science journalism is represented as undergoing seismic structural shifts relating to the demise of print media and new funding pressures (section 3.3.2.2), and science museums are responding to criticism regarding the lack of diversity of their audiences (section 5.2.1). Taken together it seems fair to describe European science communication as in a transitional phase. More research is needed into the shifts within science journalism, the rise of PR and more promotional forms of science communication (sections 2.3.3; 3.3.2.2), and the affordances and uses of social media (section 4.5), in particular. As of yet, it is unclear where these domains will end up and whether they will settle and stabilise over the coming years.



#### **6.2.4 Snapshots into a complex field**

As a closing point, it is worth pointing out the limitations of this work. While the report offers a ‘deep dive’ into four aspects of European science communication, it is clear that each of these domains, and their linkages across science communication as a whole, are highly complex and multivarious. Not least, the report has problematised the instrumental nature of much thinking about science communication, meaning that it is not obvious what notions such as ‘improving’ European science communication might mean in practice. It should be read as a starting point for future research and for reflective, experimental science communication practice.

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# APPENDIX A - SECTION 4: SCIENCE ON SOCIAL MEDIA

## A.1 DICTIONARY OF ENGAGEMENT METRICS

We use different metrics throughout this study in order to compare science communication on social media across different countries, topics and types of sources. What follows is a dictionary of the metrics used. The metrics also are associated to a level of passive or active engagement with the content depending on how much they require from the user. For example, leaving viewing a video or given a like require less effort (passive engagement) than leaving a comment (active engagement).

*Facebook Likes:* The number of likes received by a Facebook post.

*Facebook Comments:* The number of comments received by a Facebook post.

*Facebook Shares:* The number of shares received by a Facebook post.

*YouTube Views:* The number of times YouTube video was watched (not necessarily until the end).

*YouTube Likes:* The number of likes received by a YouTube video.

*YouTube Dislikes:* The number of dislikes received by a YouTube video.

*YouTube Comments:* The number of comments received by a YouTube video.

*Twitter Retweets:* The number of times a tweet has been retweeted.

*Twitter Favorites:* The number of favorites a tweet has received.

Given the previous engagement metrics and all the data provided by the social media platforms we can also calculate more complex metrics.

*Overall Engagement:* The raw metric that measures the number of users that interact with the content, like the number of likes, comments, shares, dislikes, views, reweets or favorites received by a given piece of content.

*Engagement Volume:* we calculate it as the overall engagement of a given metric (for example the number of likes received by a post) divided by the number of users who subscribe to that account (for example the



number of fans on the Facebook page that created that post). To obtain the volume on Facebook we make use of the number of fans of the Facebook page, on Twitter we use the number of followers of the account and on YouTube we use the number of subscribers to the channel.

Concepts and Number of Concepts present in the post/video/tweet: When using the Watson Natural Language API we analyze a chosen text and obtain a number of high-level concepts. These concepts are keywords that summarize the given text. For example, a research paper about deep learning might return the concept, "Artificial Intelligence" although the term is not mentioned at all in the text.

Sentiment of the Comments: it analyzes the general sentiment of the comment returning a sentiment polarity (positive, neutral or negative) and a sentiment score, a value ranging from -1 to 1, where 0 corresponds to a neutral sentiment, and the more negative or positive a value is, the more negative or positive the sentiment of the text is.

# APPENDIX B - SECTION 4: SCIENCE ON SOCIAL MEDIA

## B.1 DATA DETAILS

The following table shows the size of the dataset considering the country and the platform.

Table 1 - Size of the dataset by country.

	DE	EE	EU	FR	IE	IT	NO	UK
<i>Facebook Pages</i>	65	41	41	65	39	136	38	73
<i>Facebook Posts</i>	154,975	41,169	65,391	115,532	71,905	343,552	64,412	186,198
<i>Facebook Comments</i>	674,429	17,610	98,653	373,421	129,000	799,119	81,723	481,159
<i>YouTube Channels</i>	55	18	36	55	33	105	28	63
<i>YouTube Videos</i>	15,463	2,081	9,863	16,474	10,362	32,894	4,063	28,217
<i>YouTube Comments</i>	4,093,260	1,151	87,234	123,948	15,801	346,415	2,665	761,937
<i>Twitter Accounts</i>	88	15	55	94	59	160	49	141
<i>Twitter Tweets</i>	24,541	810	29,369	39,270	22,214	60,496	7,764	124,144

For Facebook we have the number of Facebook pages (these can be found in the list of sources), the number of posts downloaded from those pages by country and the total number of comments given to those posts. For YouTube we have the number of YouTube channels (these can be found in the list of sources), the number of videos downloaded from those channels by country and the total number of comments given to those videos. For Twitter, as the data access is more restricted, we have the number of Twitter accounts (these can be found in the list of sources) and the total number of tweets published by those accounts by country. Unfortunately, the Twitter API does not allow access to the replies of a tweet and that data cannot be downloaded. The number of Twitter accounts might not match the number of accounts on the list, due to the fact that not all accounts might have been active during the download period.

## B.2 MAIN CONCEPTS OF 2019 WITHIN THE TEXT

### B.2.1 Main Concepts of 2019 on Facebook

Figure 1 shows the most frequent concepts found on Facebook for each country for all posts published in 2019, that is, the topics that are more present for the first semester of 2019. In the case of Norway and Estonia the number of relevant extracted concepts is low due to the fact that Estonian and Norwegian are not supported by the Watson NLU software, only the few posts that were in the supported languages were analyzed. Estonia has a total of 238 concepts and Norway has 592, while the rest is considerably higher (Germany has 3028, EU has 2384, France has 2342, Ireland has 2139, Italy has 6362 and the UK has 5917).

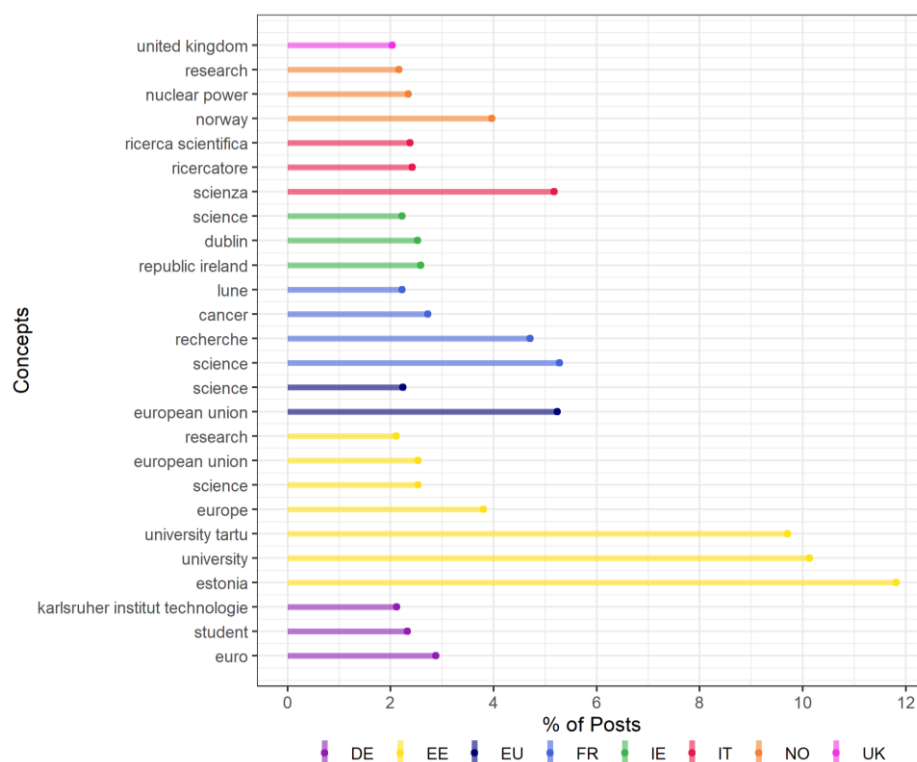


Figure 1 - Concepts that appear on more than 2% of the posts of each country published in 2019 on Facebook. On the x-axis we can see the percentage of posts of that country that match the concept. Note that while most countries had more than 2k concepts, Estonia and Norway, due to the lack of language support only had 238 and 592 respectively.

Figure 2 shows the top 75 concepts in terms of appearance on the posts published on Facebook on 2019.



Figure 2 - Word clouds of the concepts that show up on the Facebook posts of 2019 by country. The size and color intensity of the concepts are proportional to their frequency. Note that while most countries had more than 2k concepts, Estonia and Norway, due to the lack of language support only had 238 and 592 respectively.

### B.2.2 Main Concepts of 2019 on YouTube

Figure 3 shows the most frequent concepts found on YouTube for each country for all videos published in 2019, that is, the topics that are more present for the first semester of 2019.

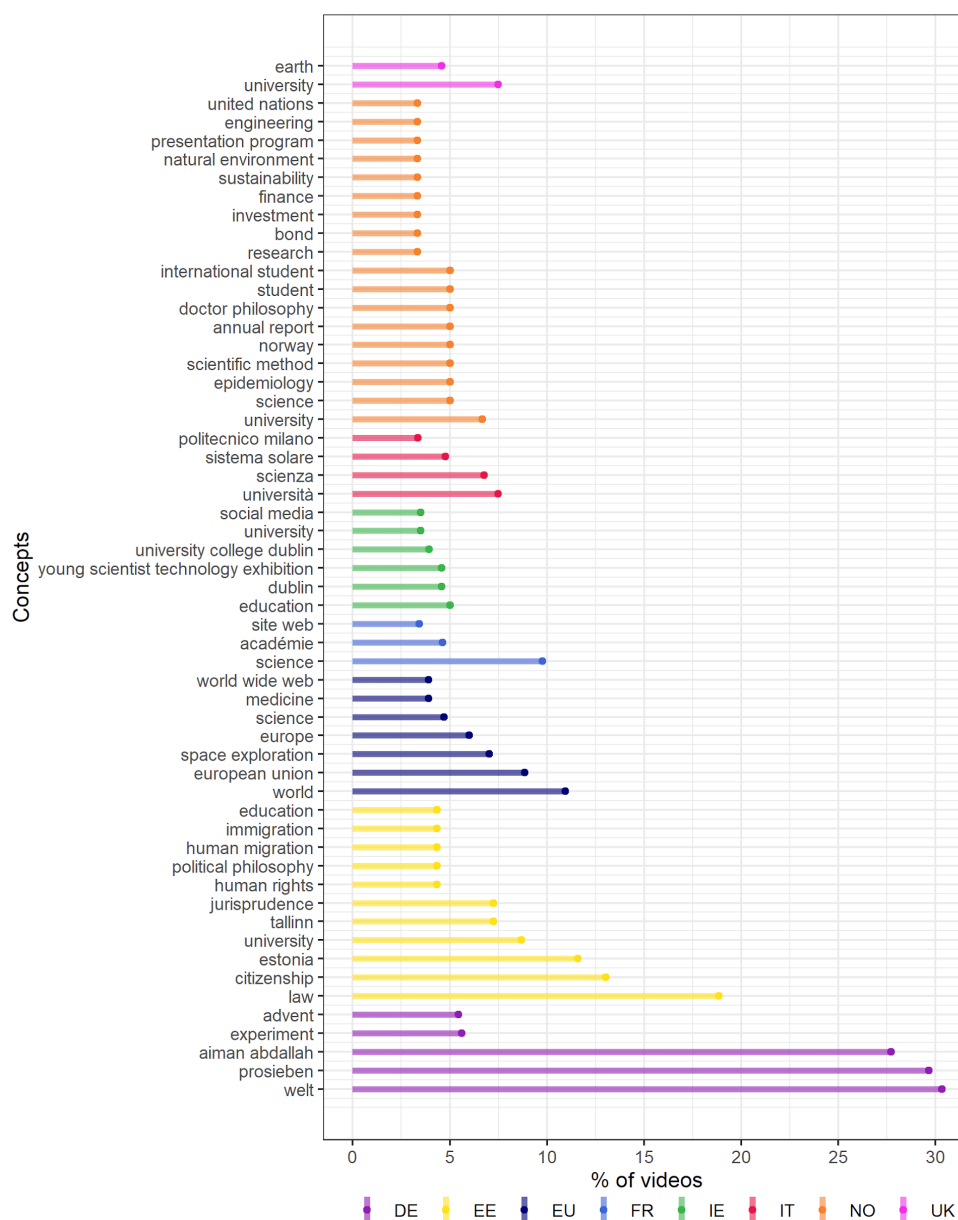


Figure 3 - Concepts that appear on more than 3.3% of the title and description of the videos of each country published in 2019 on YouTube. On the x-axis we can see the percentage of videos of that country that match the concept. Note that while most countries had more than hundreds of concepts, Estonia and Norway, due to the lack of language support only had 74 and 77 respectively.

Once again, for Norway and Estonia the number of relevant extracted concepts is low due to the fact that Estonian and Norwegian are not supported by the Watson NLU software, only the few videos whose title and descriptions

were in the supported languages were analyzed. Estonia has a total of 74 concepts and Norway has 77, while the rest is considerably higher (Germany has 814, EU has 344, France has 991, Ireland has 422, Italy has 1397 and the UK has 1151).

Figure 4 shows the top 75 concepts in terms of appearance on the videos published on YouTube on 2019.

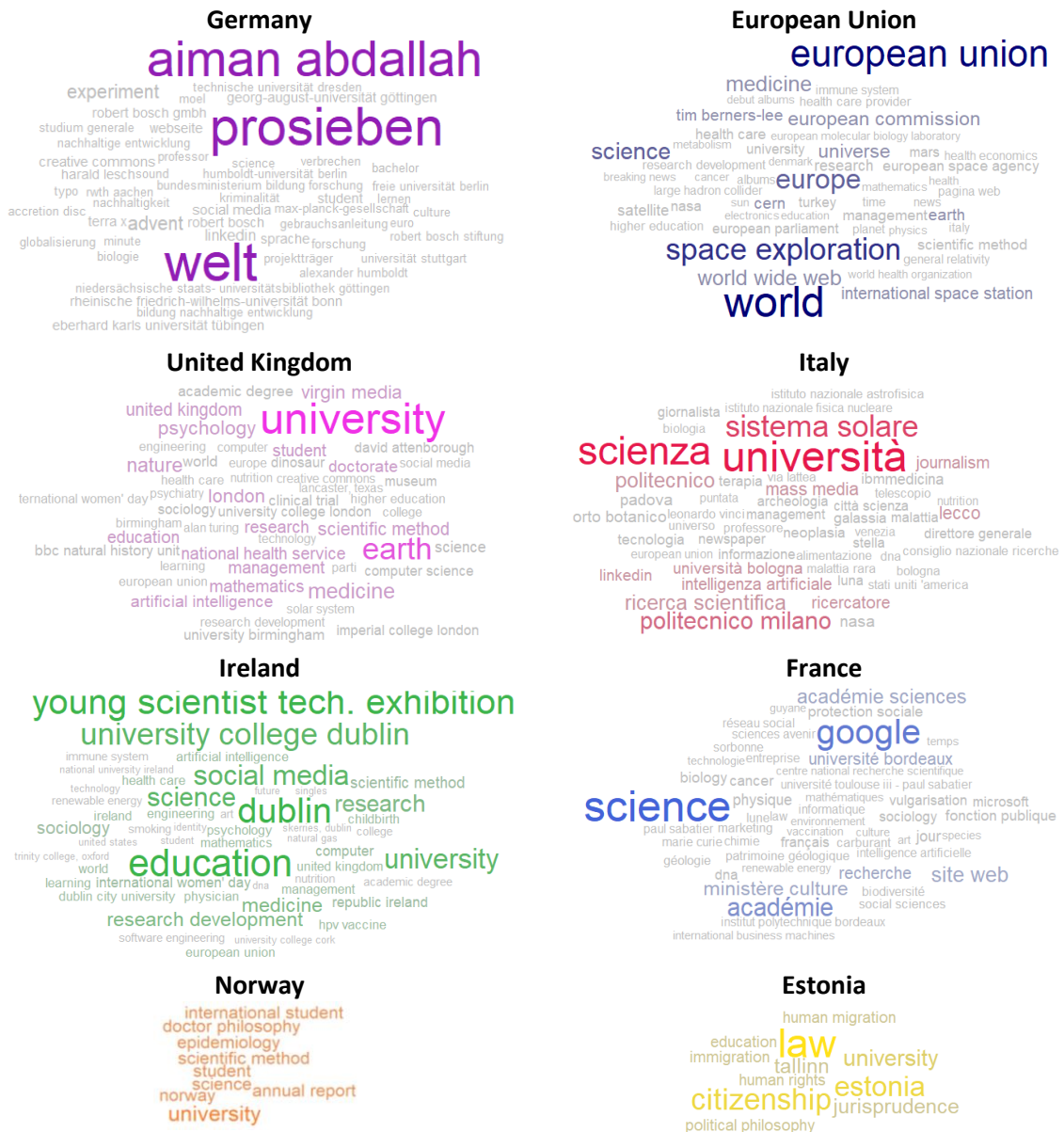


Figure 4 - Word clouds of the concepts that show up on the YouTube videos of 2019 by country. The size and color intensity of the concepts are proportional to their frequency. Note that while most countries had more than 100 concepts, Estonia and Norway, due to the lack of language support only had 74 and 77 respectively.

### B.2.3 Main Concepts of 2019 on Twitter

Figure 5 shows the most frequent concepts found on Twitter for each country for all tweets in the dataset.

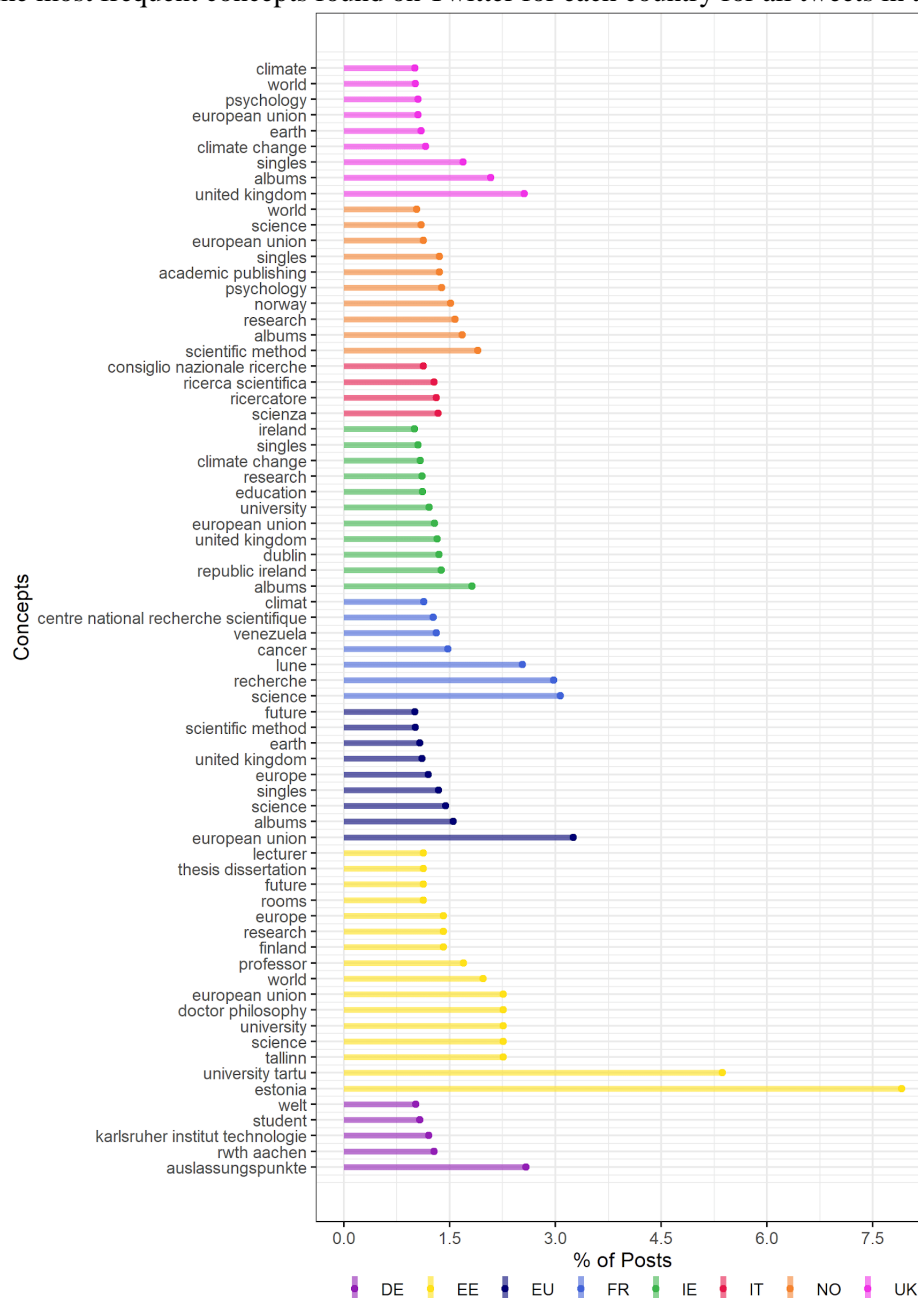
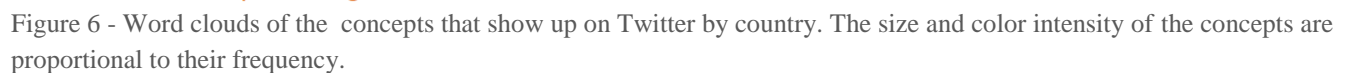


Figure 5 - Concepts that appear on more than 1% of the tweets of each country. On the x-axis we can see the percentage of tweets of that country that match the concept. Note that while most countries had more than hundreds of concepts, Estonia and Norway, due to the lack of language support only had 340 and 2045 respectively.





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considerably higher (Germany has 5783, EU has 7226, France has 5757, Ireland has 5957, Italy has 9034 and the UK has 18396).

Figure 6 shows the top 75 concepts in terms of appearance on the posts published on Facebook on 2019.

## B.3 OVERALL ENGAGEMENT AND ENGAGEMENT VOLUME

### B.3.1 Facebook: Overall Engagement and Engagement Volume

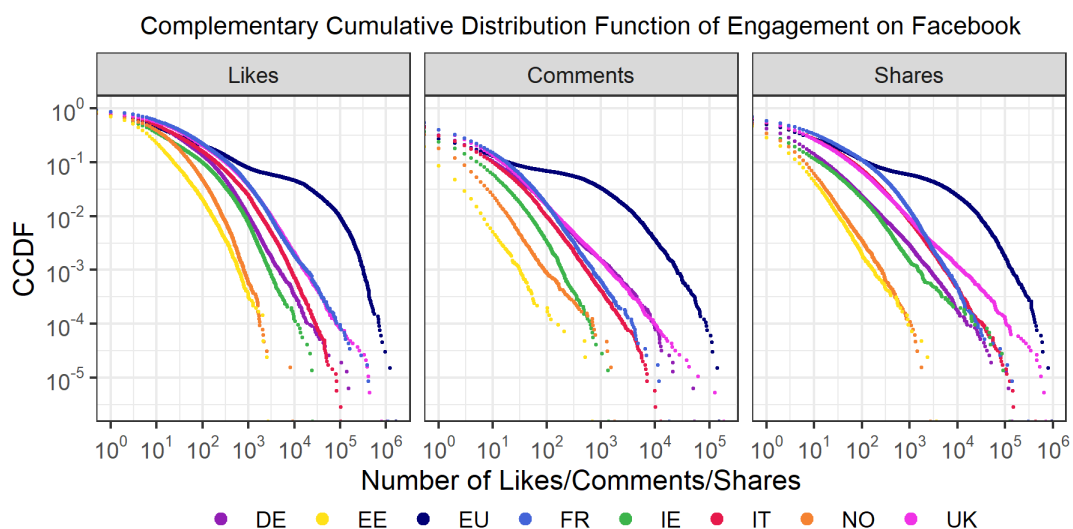


Figure 7 - Complementary Cumulative Distribution Function of Engagement Metrics on Facebook for each country. Shows the probability of a post getting x or more of the given engagement metric.

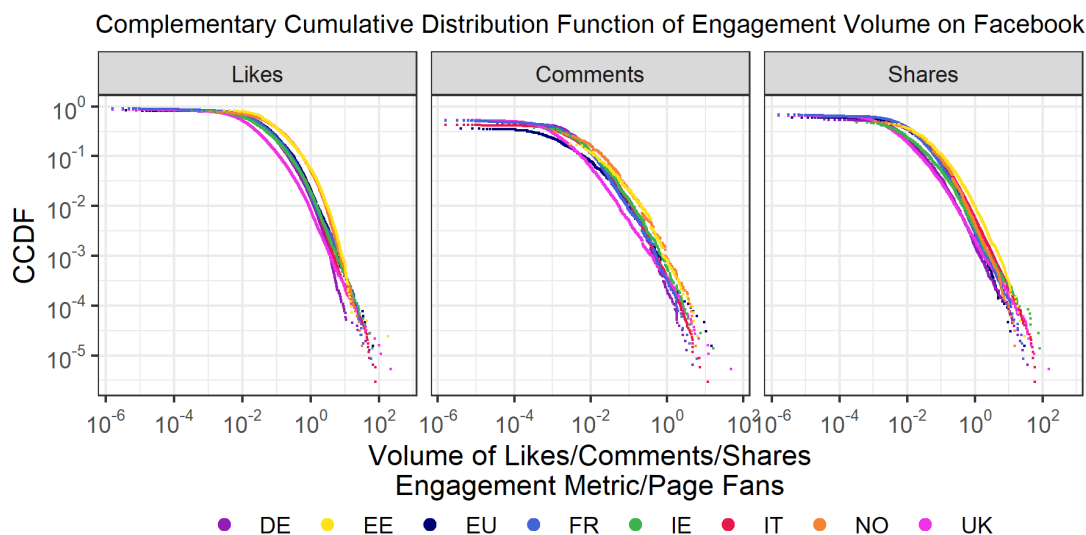


Figure 8 - CCDF of Engagement Volume on Facebook by Country. E.V. was calculated as the number of likes (or comments or shares) received by a post, divided by the number of fans of the Facebook page that published that posts.

### B.3.2 YouTube: Overall Engagement and Engagement Volume

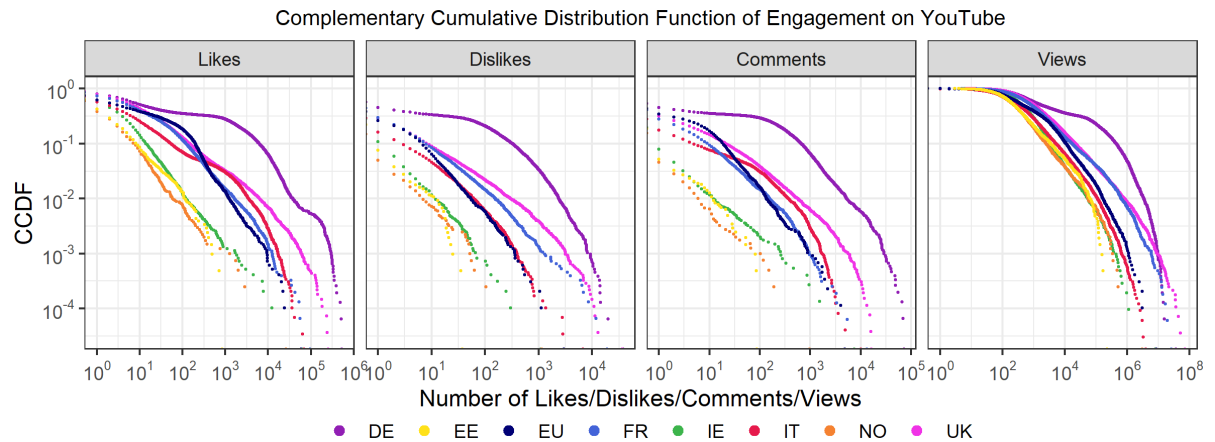


Figure 9 - Complementary Cumulative Distribution Function of Engagement Metrics on YouTube for each country. Shows the probability of a video getting x or more of the given engagement metric.

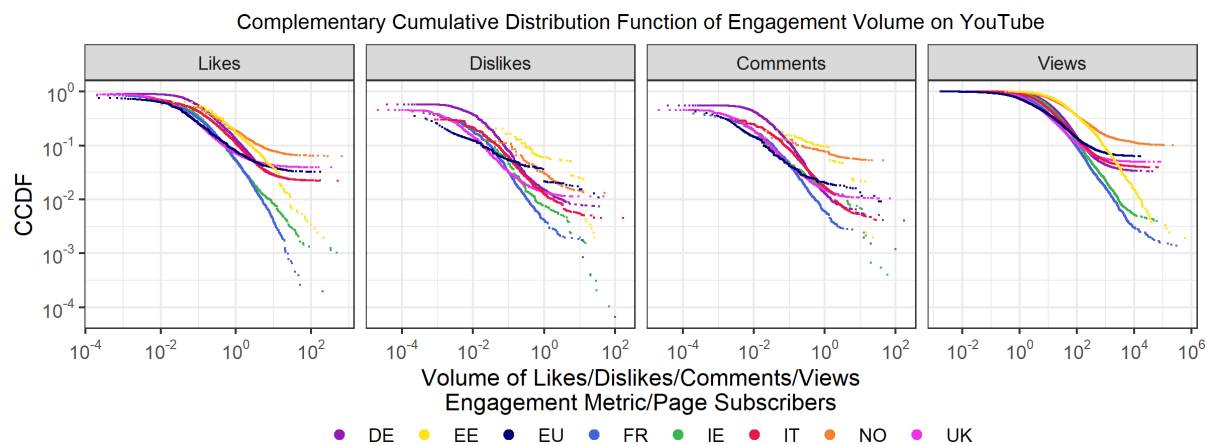


Figure 10 - CCDF of Engagement Volume on YouTube by Country. E.V. was calculated as the number of likes (or dislikes or comments, or views) received by a video, divided by the number of subscribers of the YouTube channel that published that video. It's worth noting that the number of values for Estonia (N = 2081) and Norway (N = 4062) are considerably less than for the rest of the countries (for all N > 9k).

### B.3.3 Twitter: Overall Engagement and Engagement Volume

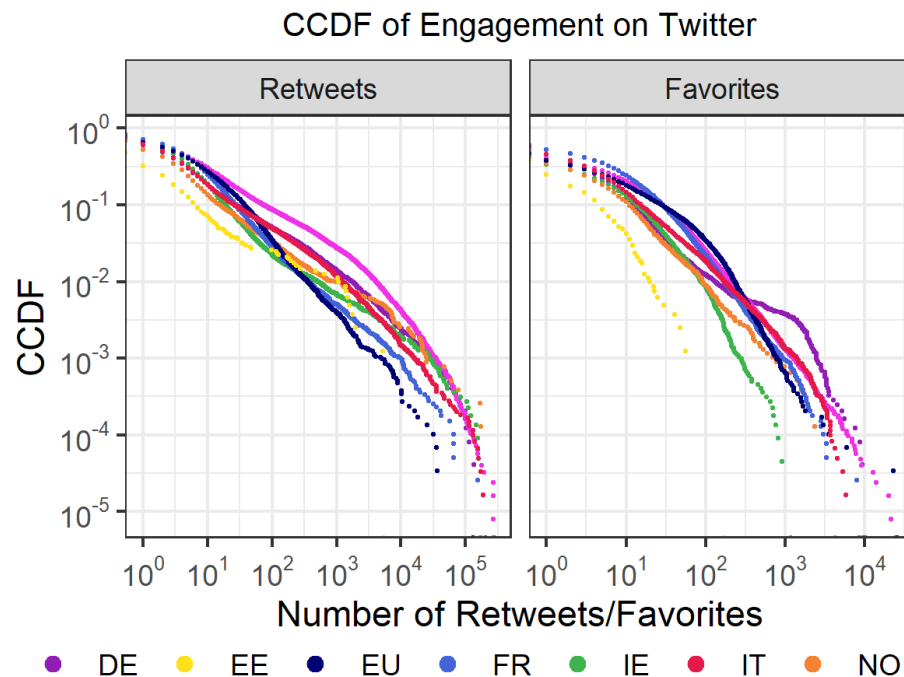


Figure 11 - Complementary Cumulative Distribution Function of Engagement Metrics on Twitter for each country. Shows the probability of a tweet getting x or more of the given engagement metric.

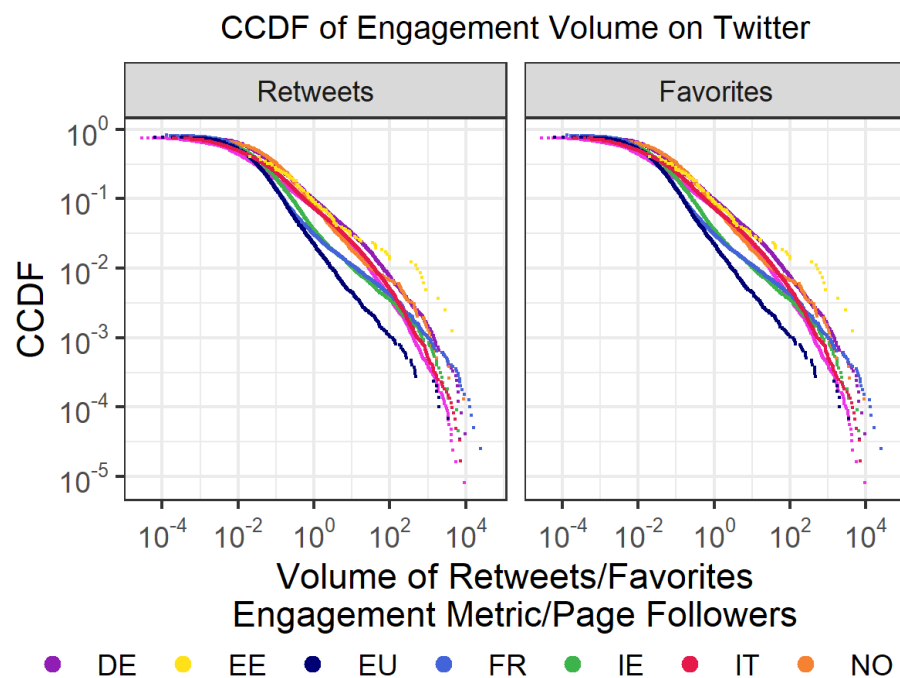


Figure 12 - CCDF of Engagement Volume on Facebook by Country. E.V. was calculated as the number of retweets (or favorites) received by a tweet, divided by the number of followers of the Twitter account that published that tweet.

## B.4 OVERALL ENGAGEMENT AND ENGAGEMENT VOLUME BY TYPE OF SCCom SOURCE

This section contains the Complementary Cumulative Distribution Function of the Overall Engagement and Engagement Volume of each platform by considering the country and the type of science communication source. Given that the presence of science communication sources differs between countries and platforms not all the figures will include everything. This is also amplified by the minimum requirement of having at least 500 measurements in each country-source type group. This could be fixed by enlarging the dataset by making more comprehensive source lists, a task that would require considerable time and effort.

### B.4.1 Facebook: Overall Engagement and Engagement Volume by Source Type

Figure 13 shows the median Engagement Volume by country and source type on Facebook posts. The E.V. is calculated as the number of likes (or comments or shares) received by a post divided by the number of fans of the respective Facebook page, then we calculate the median value of the E.V. for each country and source type pair. In grey we can see those where the E.V. is 0, in white the cases where there were no posts or we had less than 500 posts.

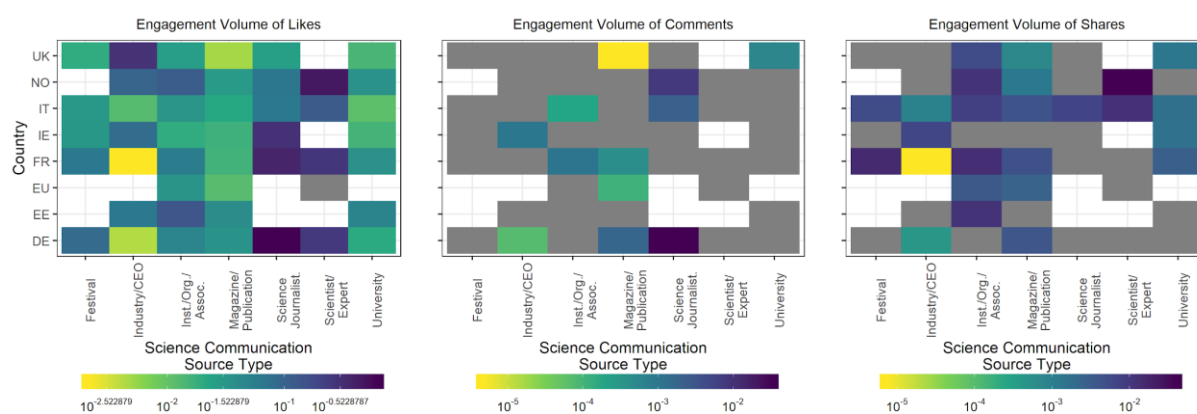


Figure 13 - Median Engagement Volume by Country and Source Type on Facebook Posts. In grey we can see those where the E.V. is 0, in white the cases where there were no posts or we had less than 500 posts. Dark purple indicates a high E.V., yellow indicates a low E.V.

Figure 14 shows the CCDF of overall Engagement Metrics and Engagement Volume on Facebook for Festivals. We can see that Italy does very well in terms of likes and shares, and Ireland is the most likely to get more comments. In terms of engagement volume (EV from now on) we find that the EU is the most engaging.

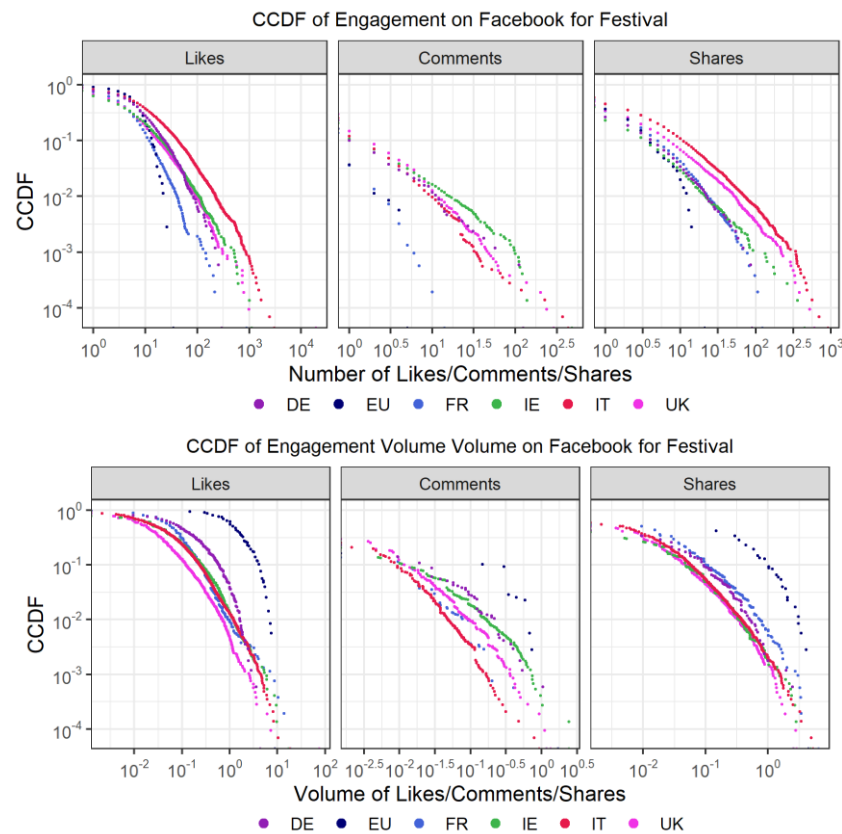


Figure 14 - CCDF of overall Engagement Metrics (top) and Engagement Volume (bottom) on Facebook for Festivals.

Figure 15 shows the CCDF of overall Engagement Metrics and Engagement Volume on Facebook for Industry/CEO. We can see that France does very well in terms of likes, comments and shares. Germany and Ireland also do very well when considering the possible audience size. In EV there are no significant differences, except perhaps for France displaying lower EV than the rest. Ireland and Germany have a good balance in terms of audience size and EV.

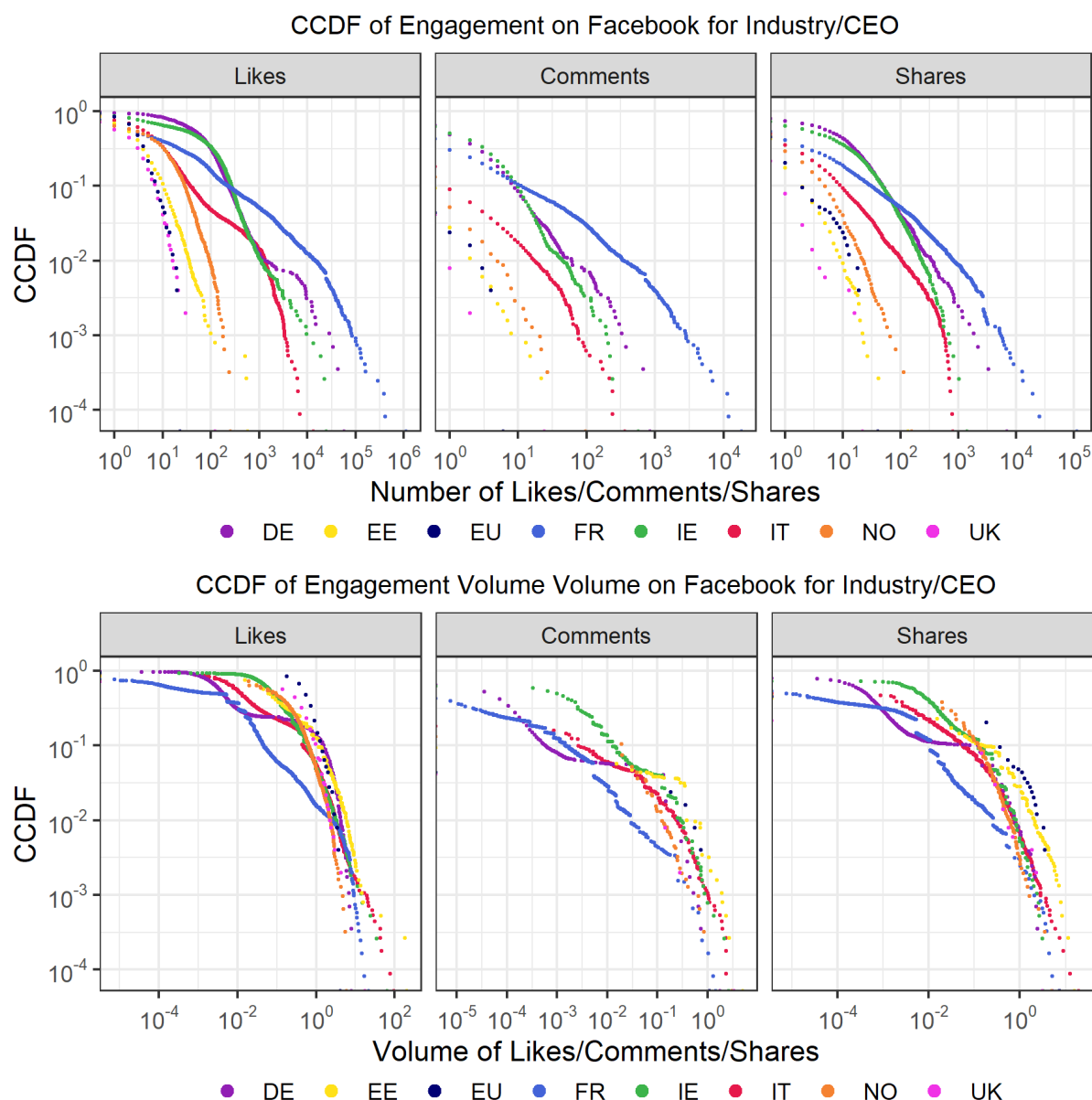


Figure 15 - CCDF of overall Engagement Metrics (top) and Engagement Volume (bottom) on Facebook for Industry/CEO.

Figure 16 shows the CCDF of overall Engagement Metrics and Engagement Volume on Facebook for Institutions, Organizations and Associations. We can see that Italy and France do very well in terms of likes, comments and shares. Estonia and Norway do very poorly, with the lowest probability of reaching more than 1k people for the likes and shares or 100 people for the comments. In EV there are no significant differences, except perhaps for Estonia and Norway displaying higher EV than the rest. Seems that while small, the audiences of Estonian and Norwegian Facebook pages of Institutions, Organizations and Associations are more engaged than in other countries.



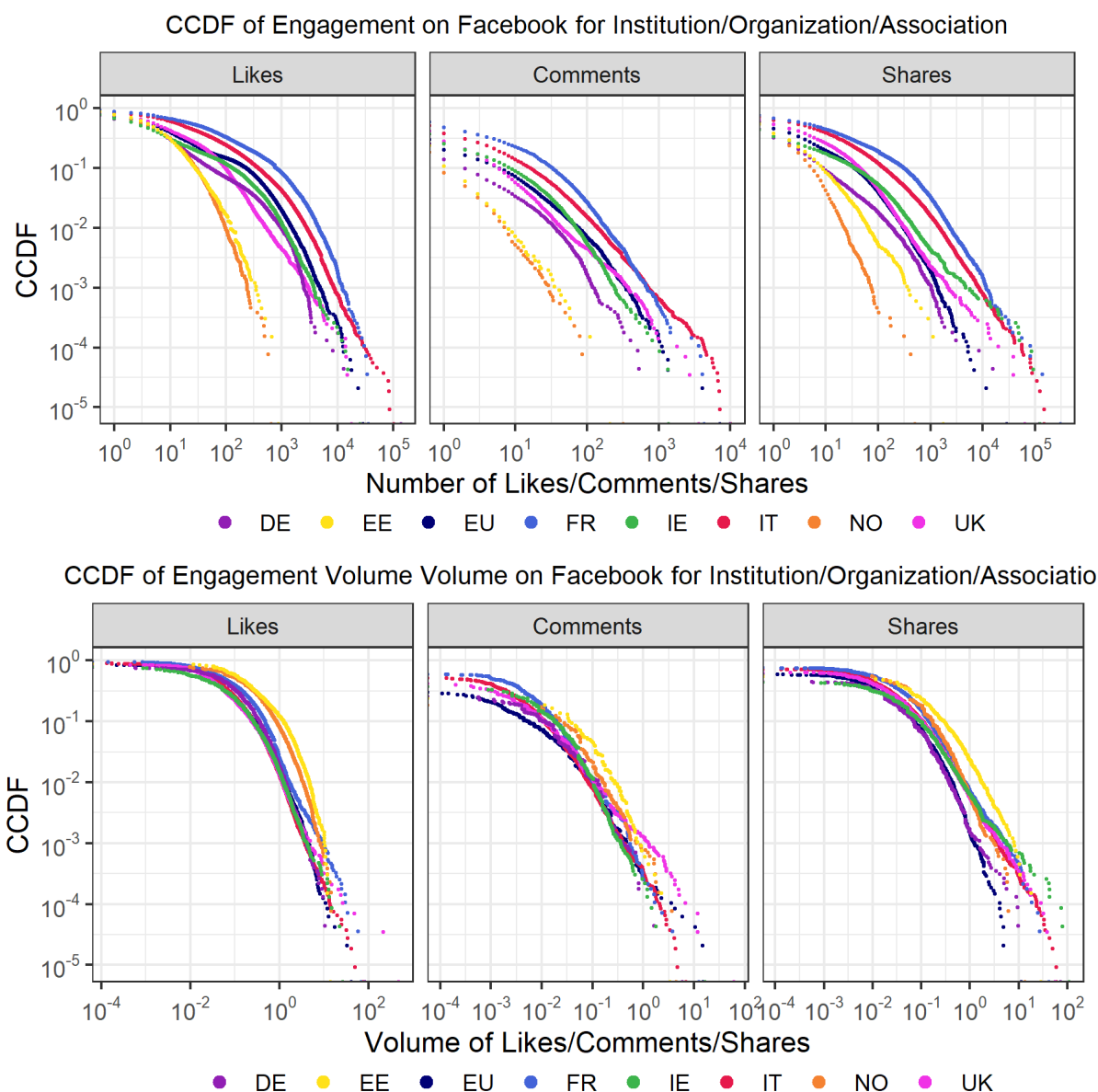


Figure 16 - CCDF of overall Engagement Metrics (top) and Engagement Volume (bottom) on Facebook for Institution/Organization/Association.

Figure 17 shows the CCDF of overall Engagement Metrics and Engagement Volume on Facebook for Magazines and Publications. We can see that EU pages do very well in terms of likes, comments and shares, with German and British pages a far second. Estonia, Norway and Ireland do very poorly, with the lowest probability of reaching more than 1k people for the likes and shares or 100 people for the comments. In EV there are no significant differences, except perhaps for Germany displaying a slightly higher EV than the rest.

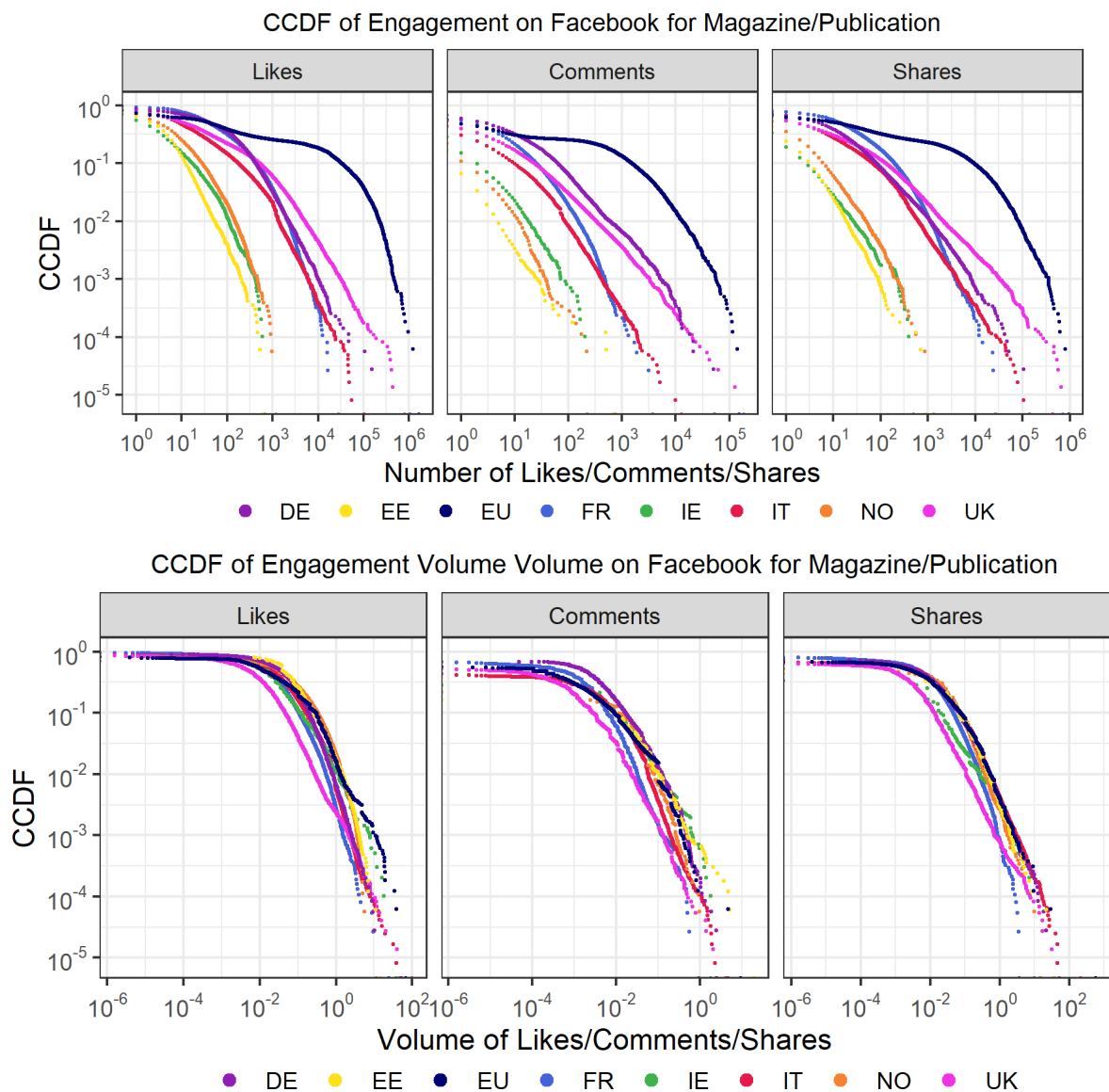


Figure 17 - CCDF of overall Engagement Metrics (top) and Engagement Volume (bottom) on Facebook for Magazine/Publication.

Figure 18 shows the CCDF of overall Engagement Metrics and Engagement Volume on Facebook for Science Journalists. We can see that Norwegian and Italian pages do very well in terms of likes and comments, and British pages do very well in terms of comments and shares. Ireland, France and Germany do poorly compared with the other three and are unlikely to get more than 30 comments or 100 likes. In EV we see some variations with Ireland and the UK being slightly more engaging than the rest, particularly when it comes to comments and shares.

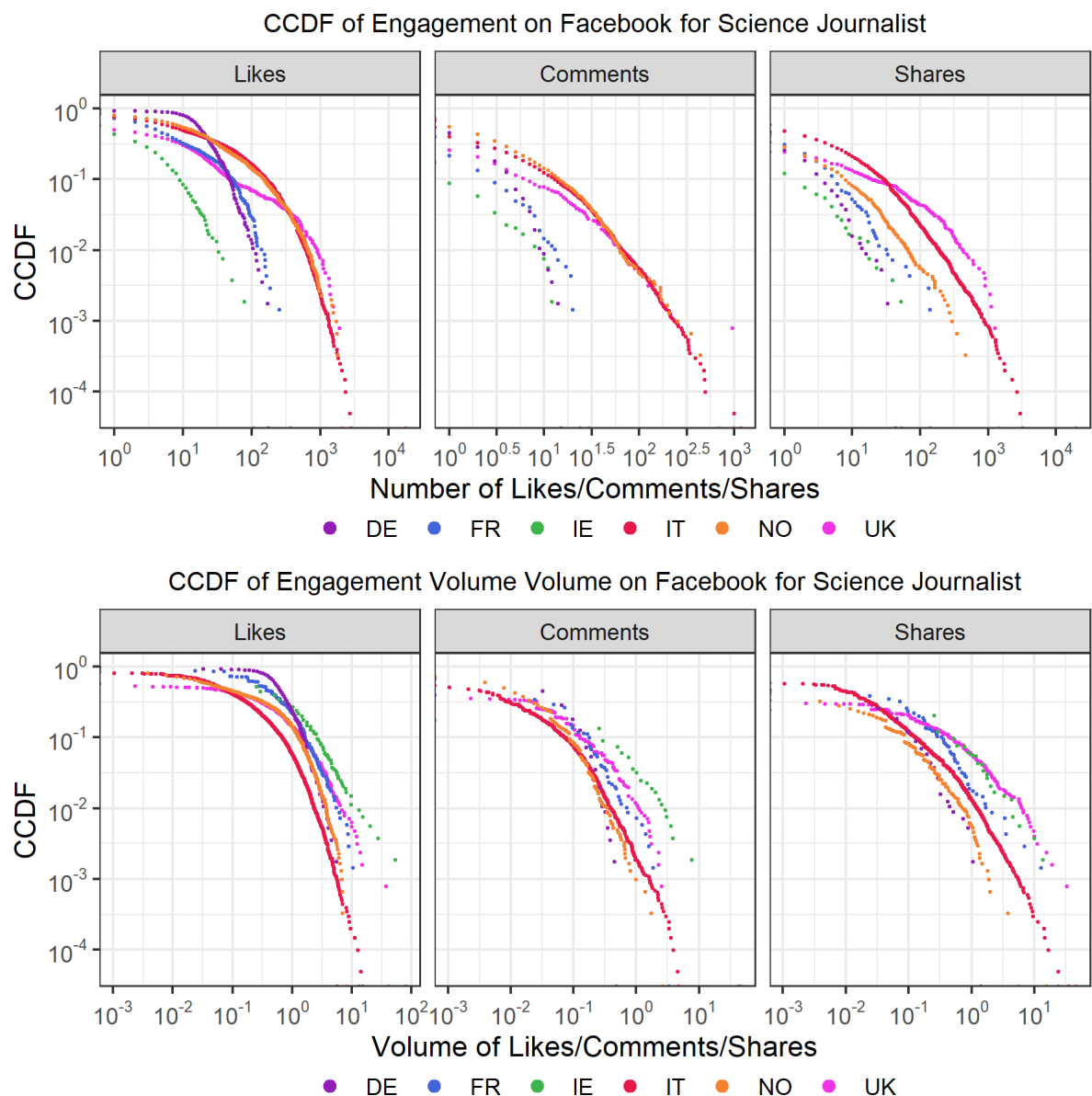


Figure 18 - CCDF of overall Engagement Metrics (top) and Engagement Volume (bottom) on Facebook for Science Journalist.

Figure 19 shows the CCDF of overall Engagement Metrics and Engagement Volume on Facebook for Scientists and experts. We can see that Italian scientists do very well in terms of all metrics. France and Germany can reach larger audiences than the rest when it comes to likes and comments, but in terms of shares Norway clearly is the one that does better after Italy. In EV there are no significant differences, except perhaps for the UK displaying a slightly higher EV than the rest.

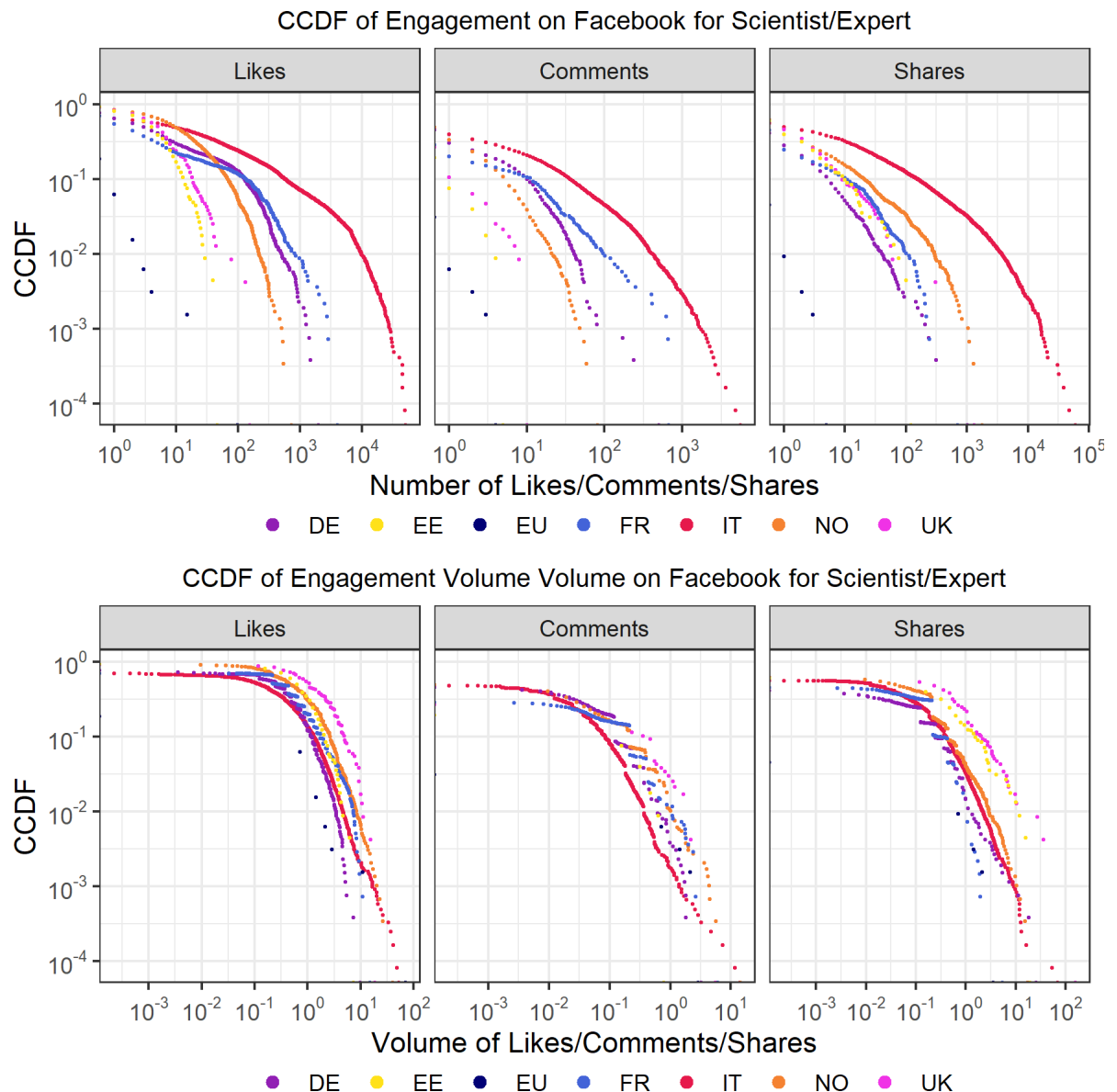


Figure 19 - CCDF of overall Engagement Metrics (top) and Engagement Volume (bottom) on Facebook for Scientist/Expert.

Figure 20 shows the CCDF of overall Engagement Metrics and Engagement Volume on Facebook for Universities. We can see that British universities well in terms of all metrics, with Irish universities being a far second when considering likes and comments. The rest are quite similar, except perhaps on the comments where we see more variation. In EV there are no significant differences, except perhaps for the Estonian universities display a slightly higher EV than the rest.

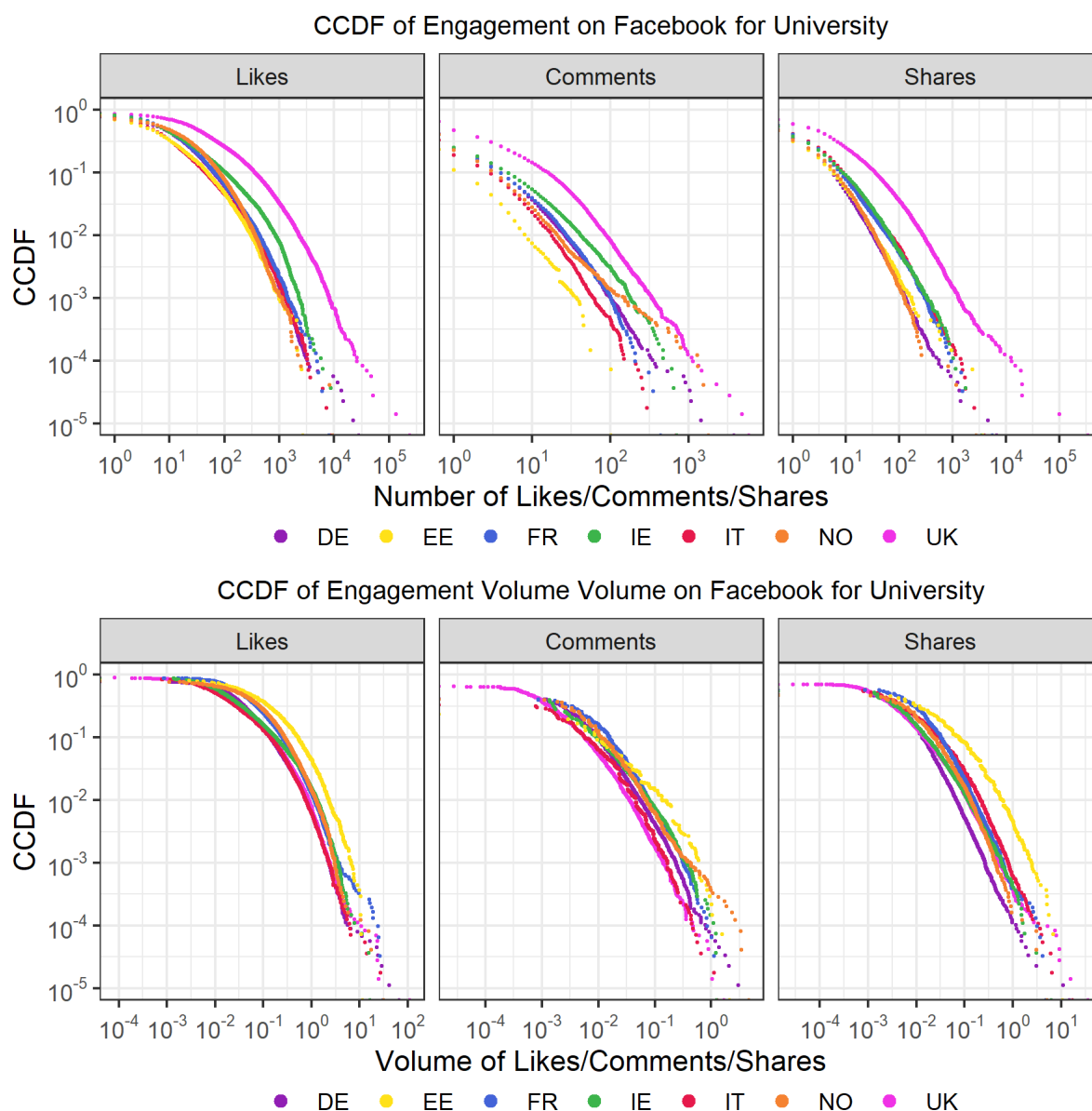


Figure 20 - CCDF of overall Engagement Metrics (top) and Engagement Volume (bottom) on Facebook for University.

### B.4.2 YouTube: Overall Engagement and Engagement Volume by Source Type

Figure 21 shows the median Engagement Volume by country and source type on YouTube videos. The E.V. is calculated as the number of likes (or dislikes or comments or views) received by a video divided by the number of subscribers of the respective YouTube channel, then we calculate the median value of the E.V. for each country and source type pair. In grey we can see those where the E.V. is 0, in white the cases where there were no videos or we had less than 100 videos.

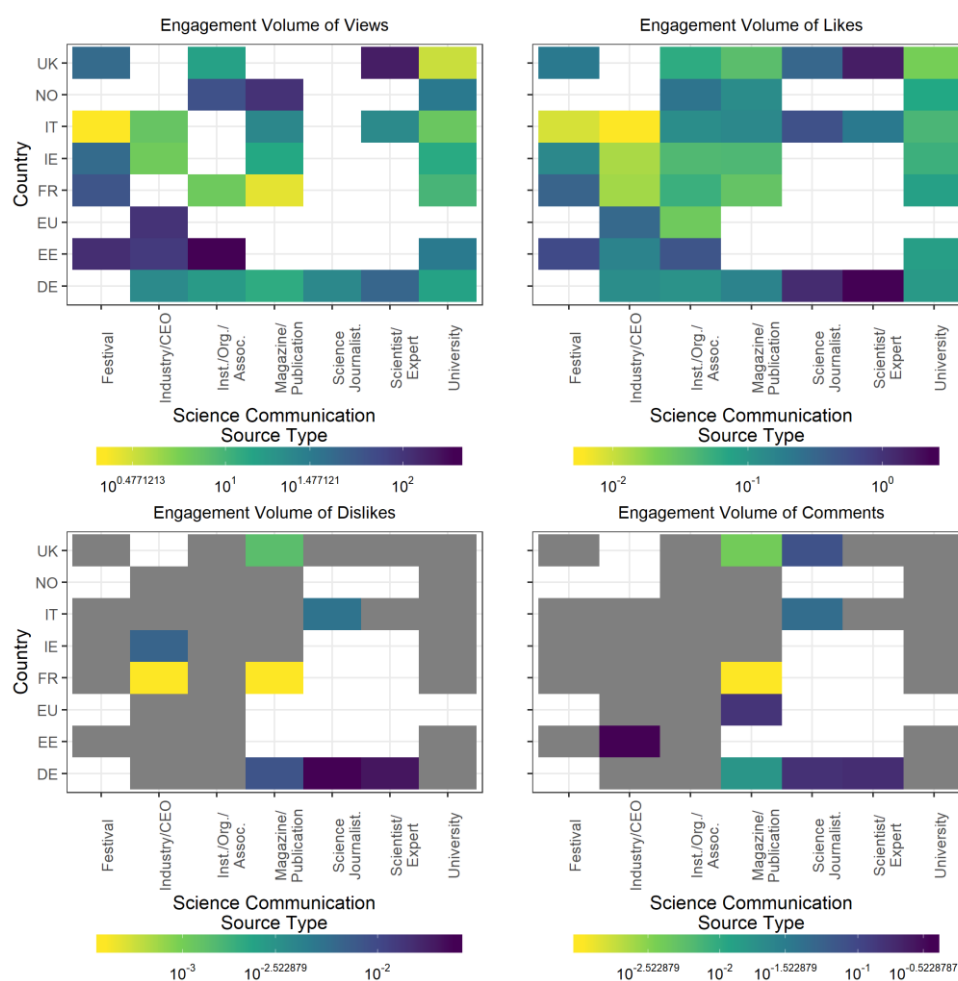


Figure 21 - Median Engagement Volume by Country and Source Type on YouTube Videos. In grey we can see those where the E.V. is 0, in white the cases where there were no videos or we had less than 100 videos. Dark purple indicates a high E.V. and yellow indicates a low E.V.

Figure 22 shows the CCDF of overall Engagement Metrics and Engagement Volume on YouTube for Festivals. We can see that the UK does very well in all metrics, having not only the highest probability of reaching big audiences but also maintains a relatively high EV when compared to the rest of the countries. Contrasting the British festivals we have Italy and France with the first having large overall engagement and low EV, and the second having low overall engagement and high EV.

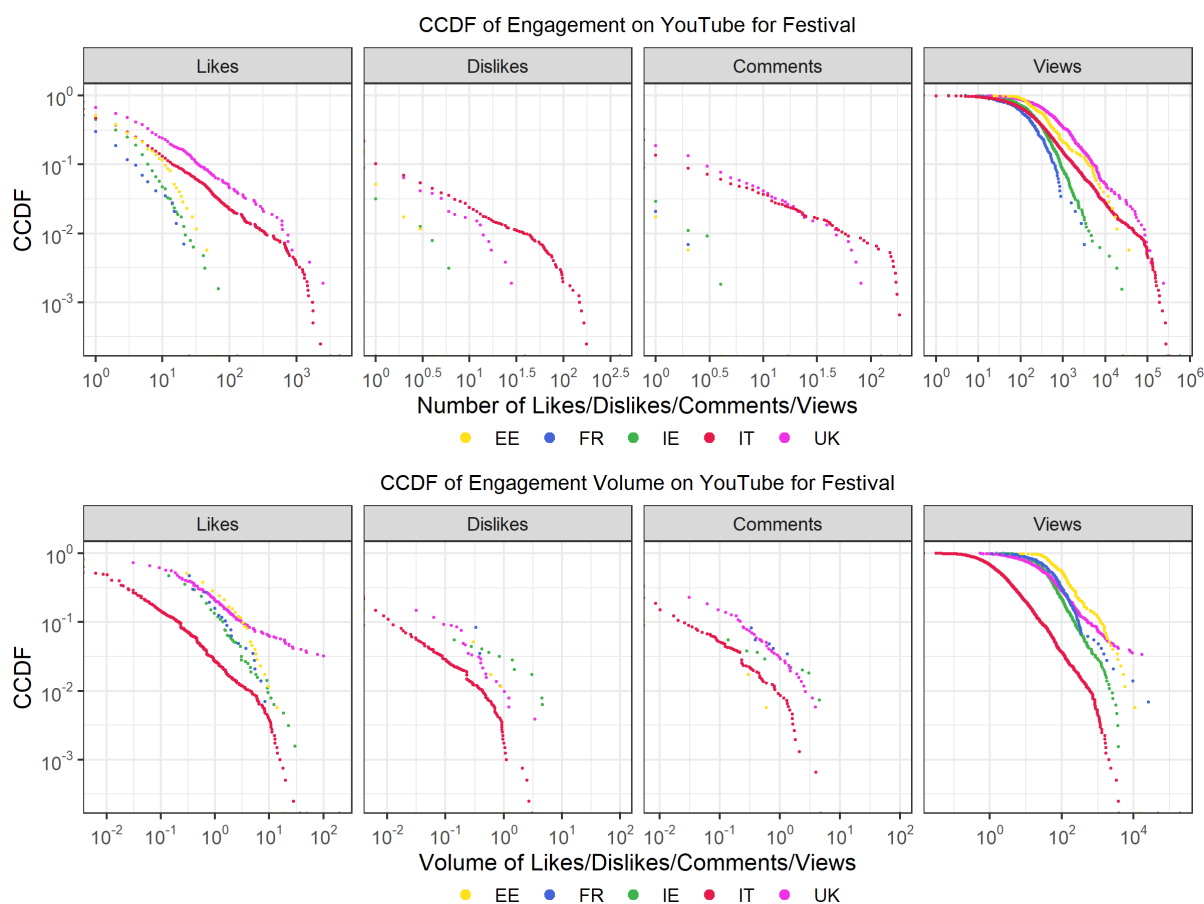


Figure 22 - CCDF of overall Engagement Metrics (top) and Engagement Volume (bottom) on YouTube for Festivals.

Figure 23 shows the CCDF of overall Engagement Metrics and Engagement Volume on YouTube for Industry/CEO. We can see that Estonia, Germany and France do very well in all metrics, having not only high probability of reaching big audiences. Looking at the EV, however, we can see that Estonia and Germany do very well and France does not. Notable is the case of the views on Norwegian channels, where the maximum number of views is quite low compared to the rest of the countries, but the EV is significantly higher.



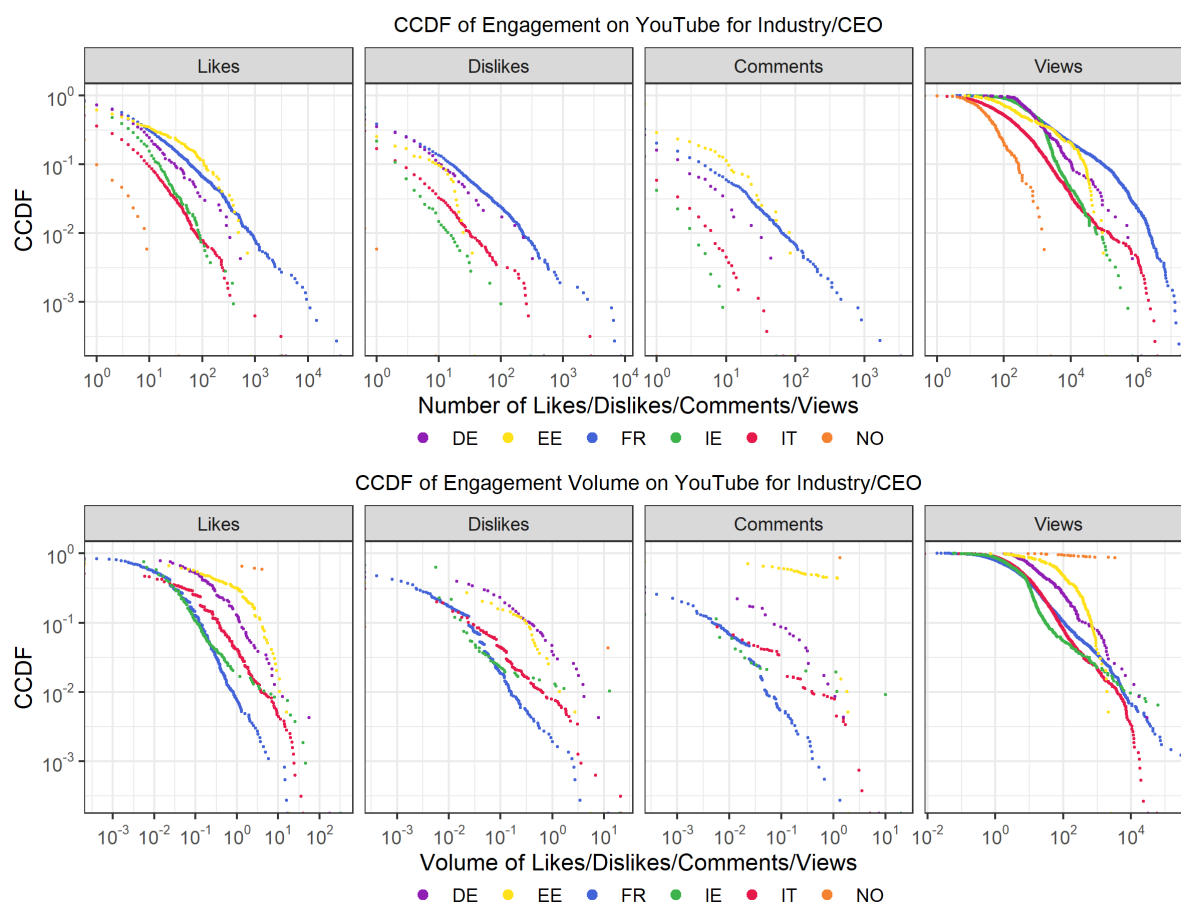


Figure 23 - CCDF of overall Engagement Metrics (top) and Engagement Volume (bottom) on YouTube for Industry/CEO.

Figure 24 shows the CCDF of overall Engagement Metrics and Engagement Volume on YouTube for Institutions, Organizations and Association. We can see that Germany does significantly better in overall engagement for all metrics and does reasonably well in EV. EU and France, however, follow the tendency of accounts reaching large audiences but these audiences being less engaged. Estonia and Norway present the highest probability of getting high EV, particularly when looking at the likes and views. This contrasts with their limited overall engagement.

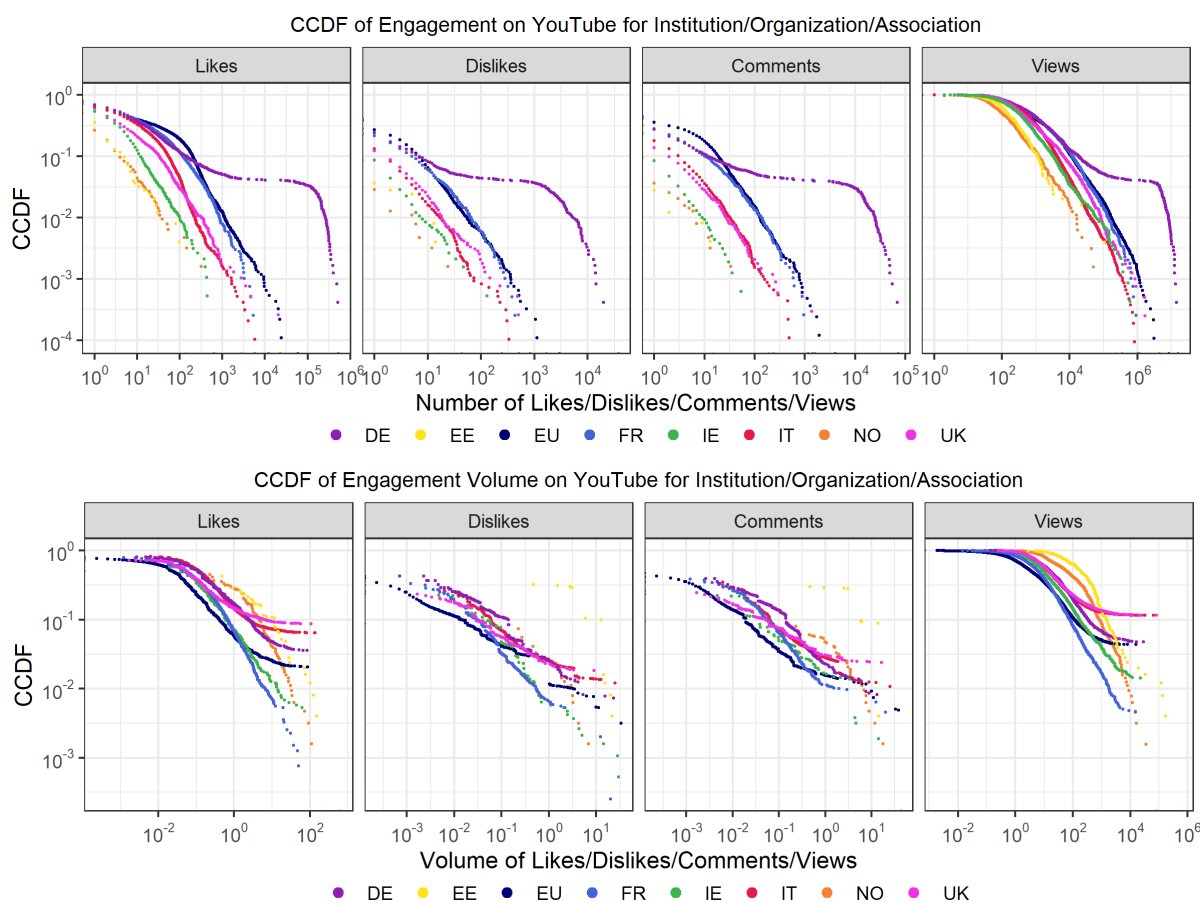


Figure 24 - CCDF of overall Engagement Metrics (top) and Engagement Volume (bottom) on YouTube for Institution/Organization/Association.

Figure 25 shows the CCDF of overall Engagement Metrics and Engagement Volume on YouTube for Magazines and Publications. We can see that Germany, the UK and France do better in overall engagement for all metrics but have low EV. The EU and Norway, however, present the opposite scenario with low overall engagement and high EV. Italy does reasonably well in both cases, overall engagement and EV, so while not attracting massive audience, the Italian users are relatively well engaged, at least compared to the other countries.

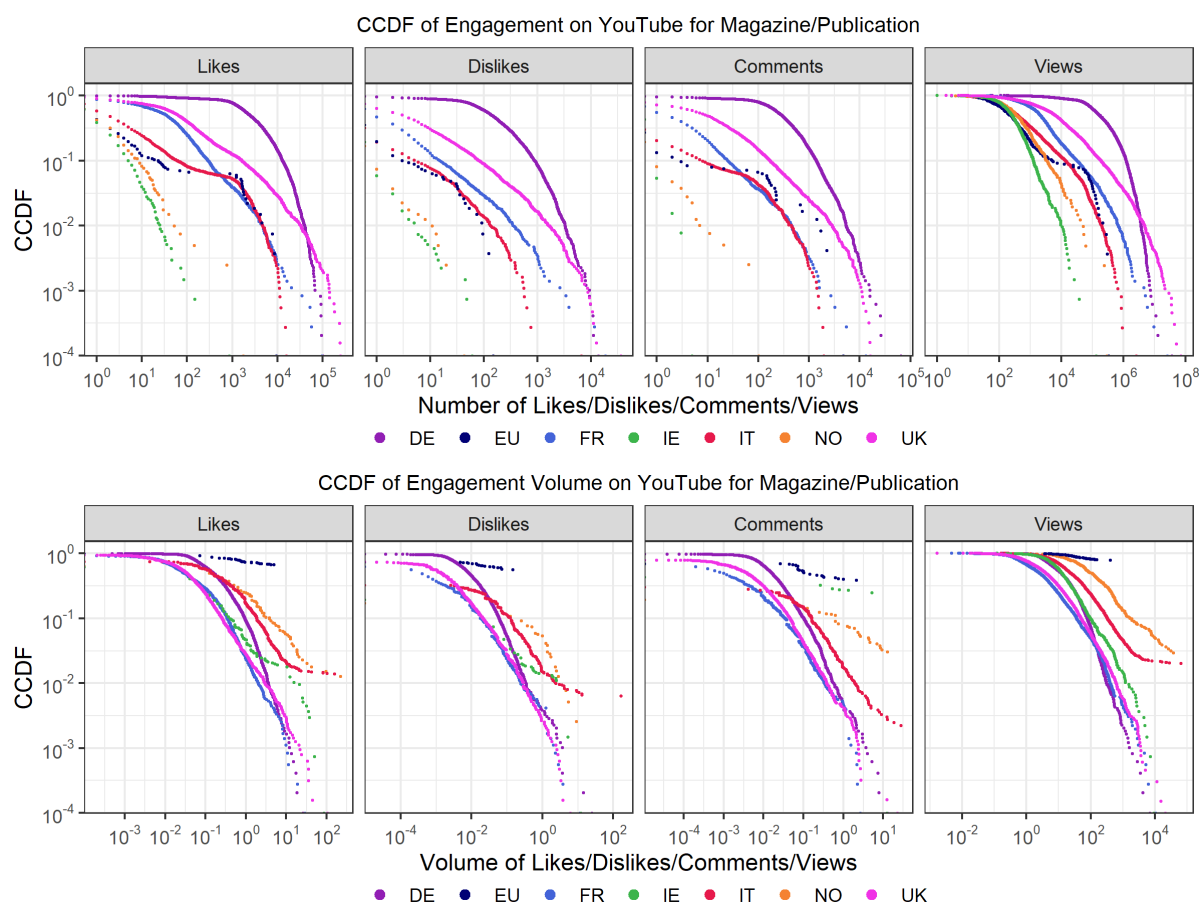


Figure 25 - CCDF of overall Engagement Metrics (top) and Engagement Volume (bottom) on YouTube for Magazine/Publication.

Figures 26 and 27 shows the CCDF of overall Engagement Metrics and Engagement Volume on YouTube for Science Journalists and Scientists/Experts, respectively. In both cases, we only have YouTube channels on three countries: Germany, the UK and Italy. We find that German and Italian Science Journalists do better than the British ones for all cases except for the EV of comments and views. Germany does slightly better than Italy, although Italy presents longer tails in the CCDFs. A similar case can be seen for the Scientists, with Germany doing great in terms of overall engagement and EV and Italy doing better than the UK in terms of overall engagement but worse in terms of EV. Both Italy and the UK present longer tails in the CCDFs of the EV than Germany, this means they are more likely to reach higher values.

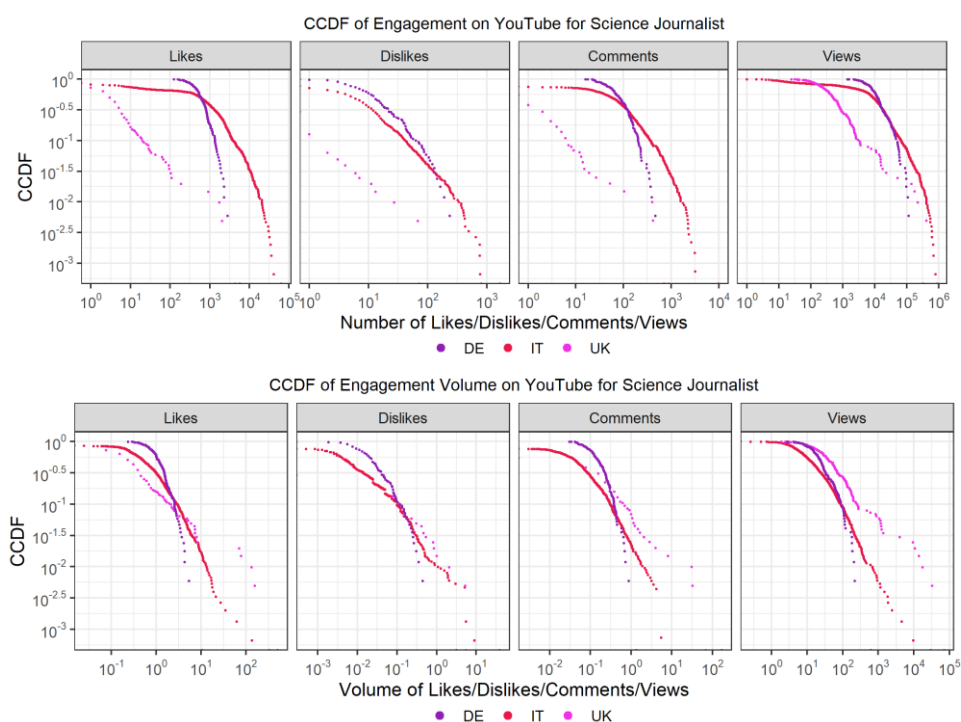


Figure 26 - CCDF of overall Engagement Metrics (top) and Engagement Volume (bottom) on YouTube for Science Journalist.

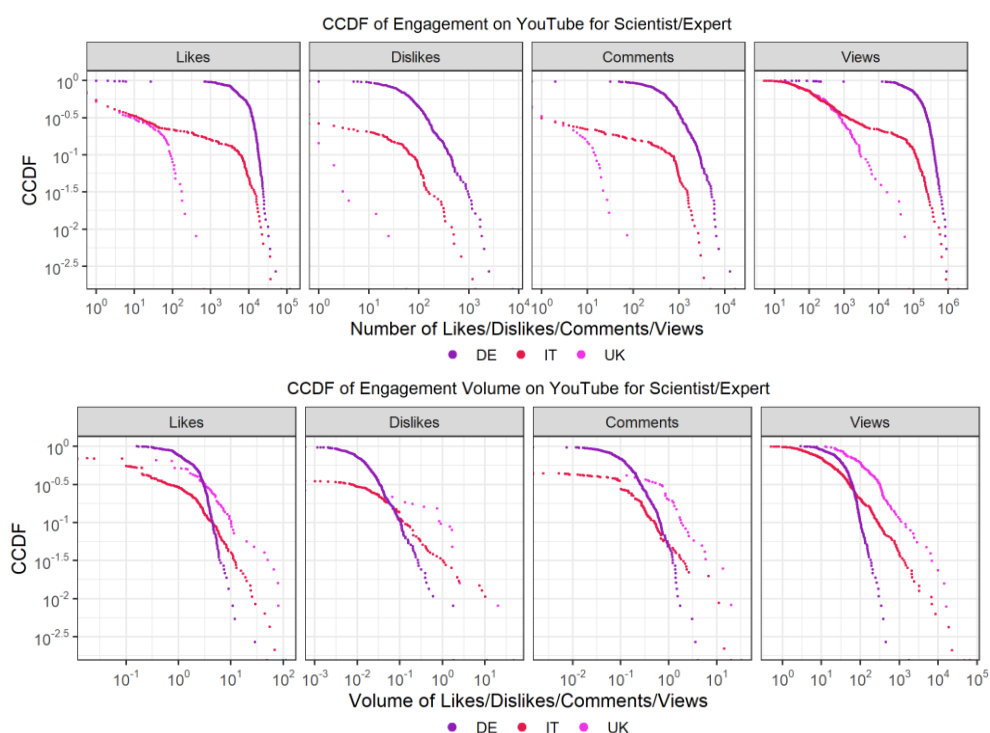


Figure 27 - CCDF of overall Engagement Metrics (top) and Engagement Volume (bottom) on YouTube for Scientist/Expert.

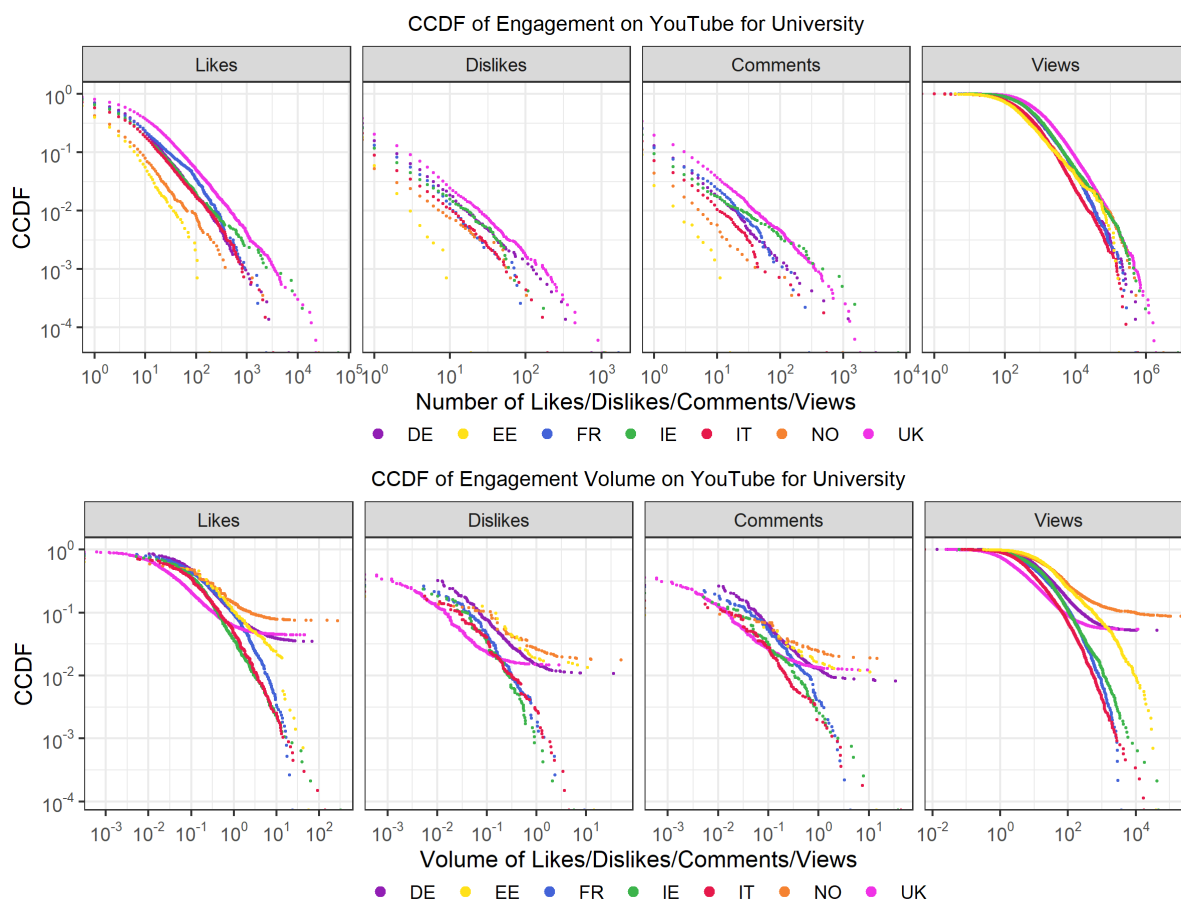


Figure 28 - CCDF of overall Engagement Metrics (top) and Engagement Volume (bottom) on YouTube for University.

### B.4.3 Twitter: Overall Engagement and Engagement Volume by Source Type

Figure 29 shows the median Engagement Volume by country and source type on tweets. The E.V. is calculated as the number of retweets (or favorites) received by a tweet divided by the number of followers of the respective Twitter account, then we calculate the median value of the E.V. for each country and source type pair. In grey we can see those where the E.V. is 0, in white the cases where there were no tweets or we had less than 500 tweets.

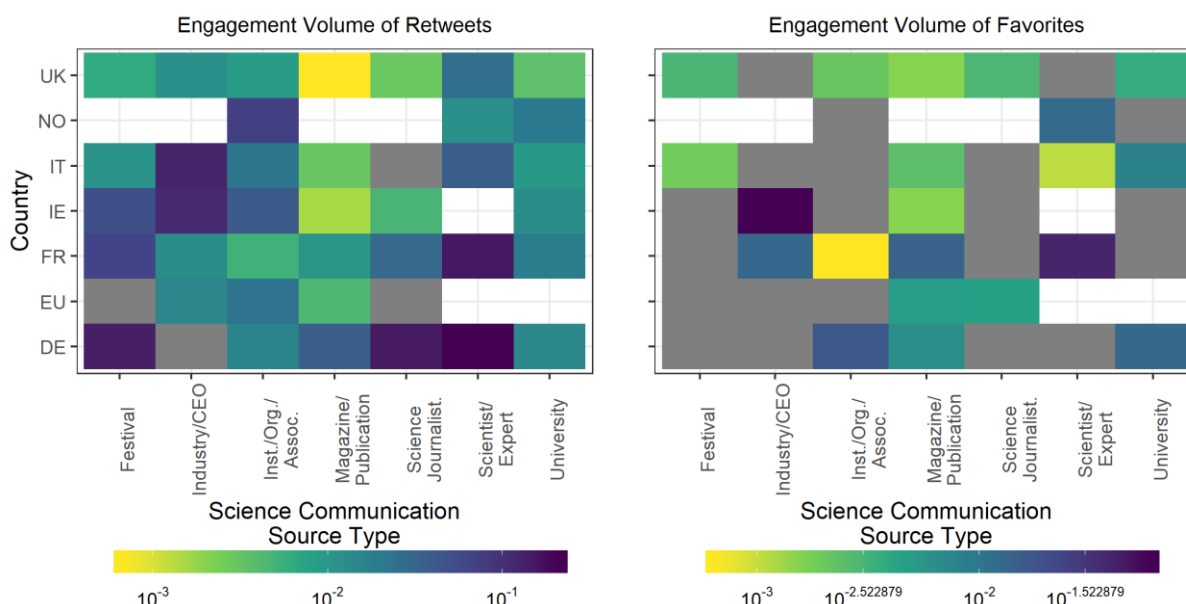


Figure 29 - Median Engagement Volume by Country and Source Type on Tweets. In grey we can see those where the E.V. is 0, in white the cases where there were no tweets or there were less than 500 tweets. Dark purple indicates a high E.V. and yellow a low E.V.

Figure 30 shows the CCDF of overall Engagement Metrics and Engagement Volume on Twitter for Festivals. We can see that Italy and France do very well in terms of retweets and favorites, and the EU the worst. When looking at the EV we can see that France displays higher EV than the rest.

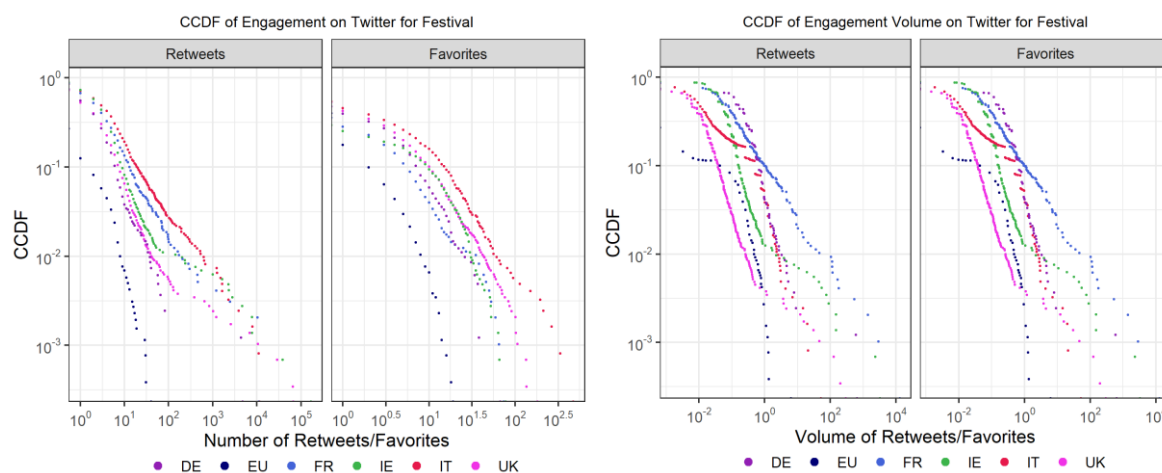


Figure 30 - CCDF of overall Engagement Metrics (left) and Engagement Volume (right) on Twitter for Festivals.

Figure 31 shows the CCDF of overall Engagement Metrics and Engagement Volume on Twitter for Industry/CEO. We can see that Italian and British tweets are more likely to be retweeted while France is more likely to get

favorites, and France do very well in terms of retweets and favorites, and the EU the worst. In terms of EV we can clearly see that Italy displays higher EV than the rest for both metrics.

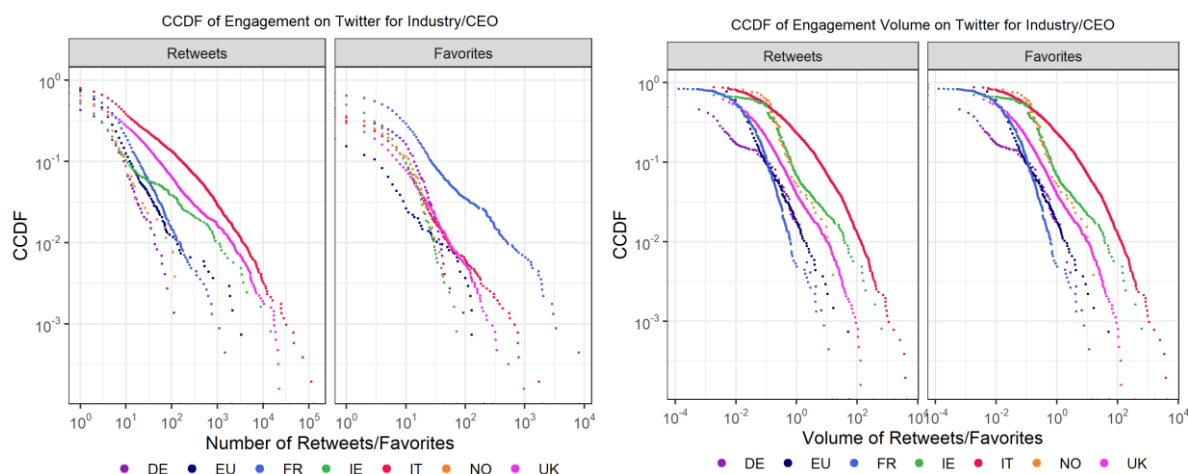


Figure 31 - CCDF of overall Engagement Metrics (left) and Engagement Volume (right) on Twitter for Industry/CEO.

Figure 32 shows the CCDF of overall Engagement Metrics and Engagement Volume on Twitter for Institutions, Associations and Organizations. There are no significant differences across countries in terms of overall engagement and EV, except for a few cases. Norwegian institutions have the lowest reach in terms of audience size, while German ones are more likely to get favorites. France institutions display a slightly lower EV than the rest.

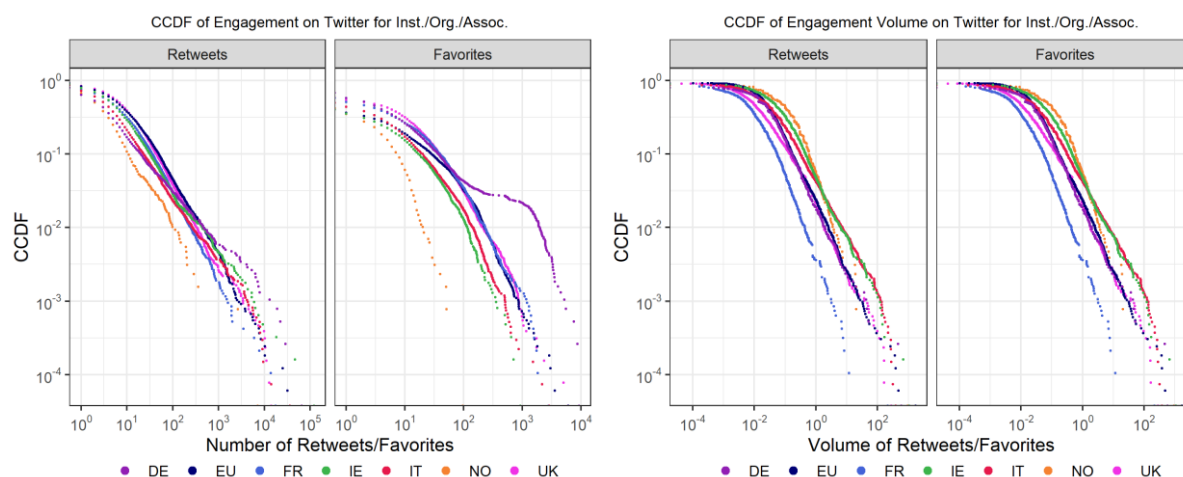


Figure 32 - CCDF of overall Engagement Metrics (left) and Engagement Volume (right) on Twitter for Institution/Organization/Association.



Figure 33 shows the CCDF of overall Engagement Metrics and Engagement Volume on Twitter for Magazines and Publications. Unlike in most cases, European publications do the best in both overall engagement and EV. This indicates not only a capability to reach wide audiences but to engage with them. Perhaps the platform factors in the increased EV. Most commonly, the UK does well in terms of overall engagement but not in EV, meaning they have possible big audiences that are not very engaged.

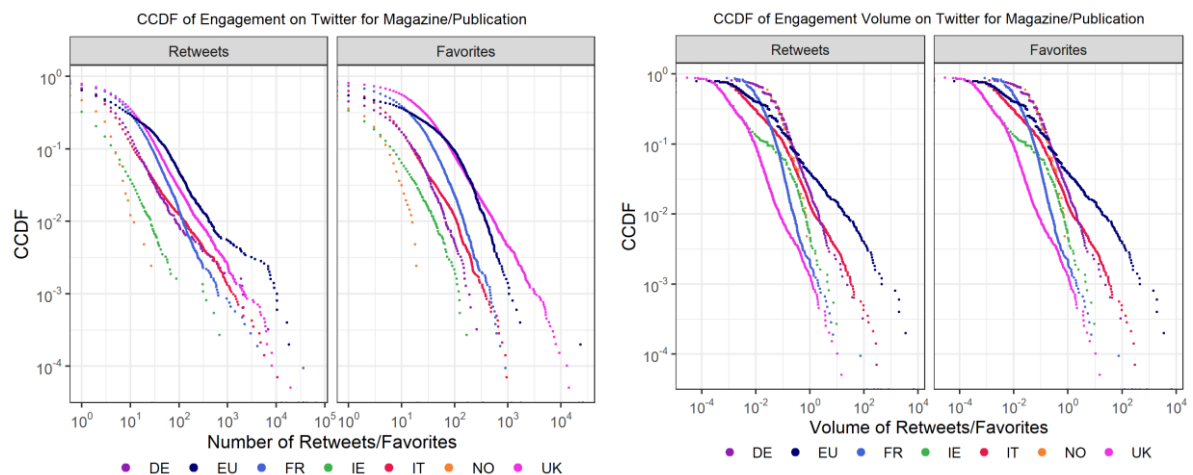


Figure 33 - CCDF of overall Engagement Metrics (left) and Engagement Volume (right) on Twitter for Magazine/Publication.

Figure 34 shows the CCDF of overall Engagement Metrics and Engagement Volume on Twitter for Science Journalists. European journalists have the lowest reach in terms of audience size (for retweets) and EV. Norwegian and German science journalists do both well in terms of overall engagement and EV for the retweets.

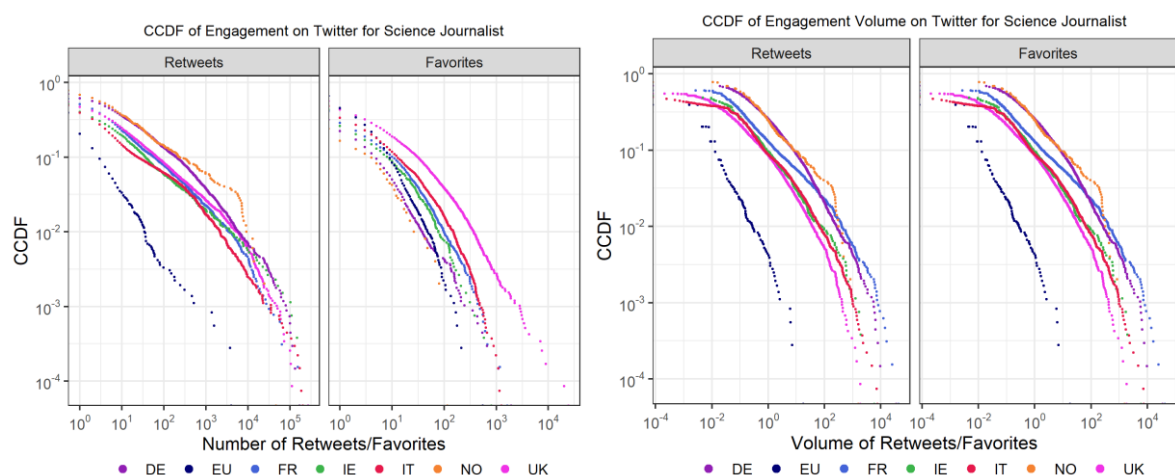


Figure 34 - CCDF of overall Engagement Metrics (left) and Engagement Volume (right) on Twitter for Science Journalist.

Figure 35 shows the CCDF of overall Engagement Metrics and Engagement Volume on Twitter for Scientists and Experts. Irish Scientist do both well in terms of overall engagement and EV for the retweets. The same can be said of the UK, Germany and Italy.

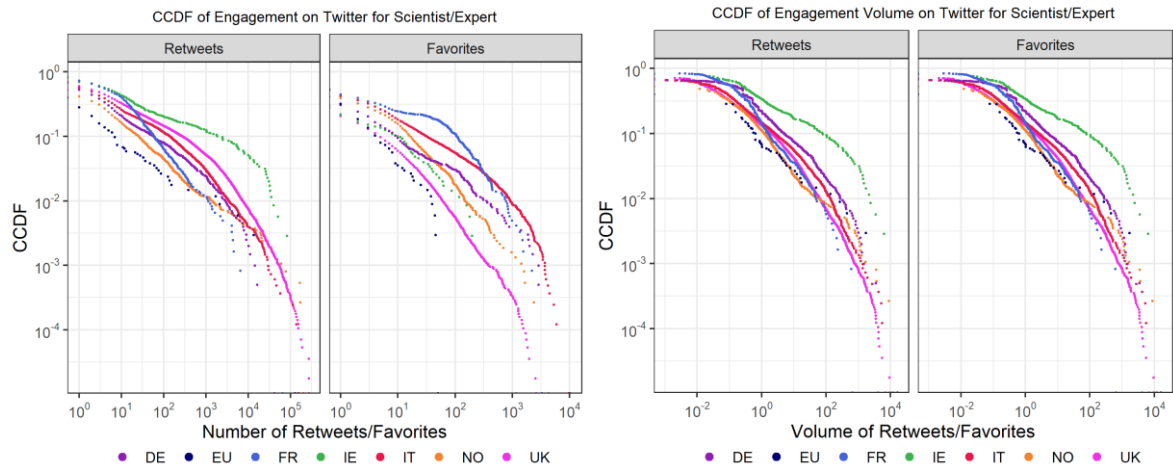


Figure 35 - CCDF of overall Engagement Metrics (left) and Engagement Volume (right) on Twitter for Scientist/Expert.

Finally, Figure 36 shows the CCDF of overall Engagement Metrics and Engagement Volume on Twitter for University. While British universities have larger audiences, followed by Irish and French universities, it's the Estonian universities that engage with their core audience the most.

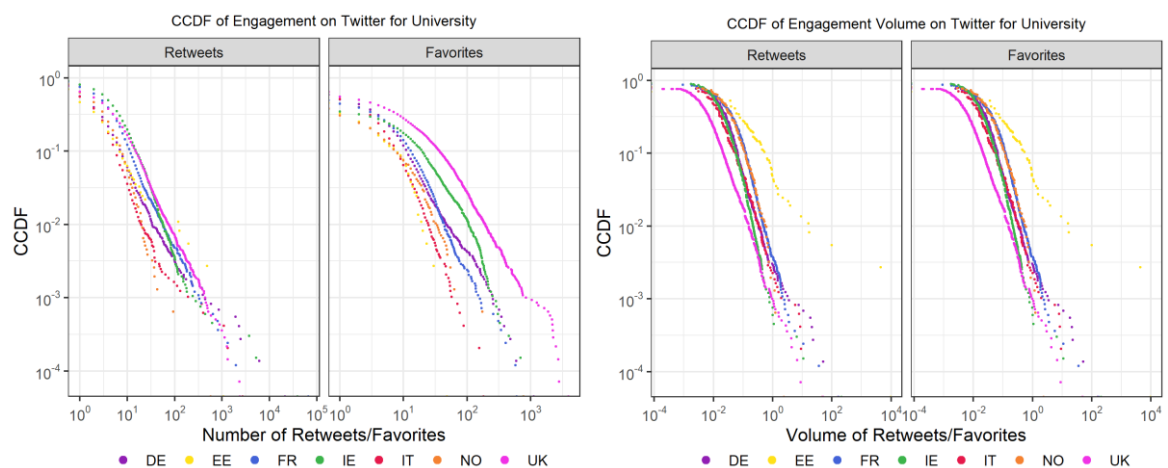


Figure 36 - CCDF of overall Engagement Metrics (left) and Engagement Volume (right) on Twitter for University.

## B.5 THE CASE STUDIES: OVERALL ENGAGEMENT AND ENGAGEMENT VOLUME

The Figures below show the Cumulative Complementary Distribution Function of the overall engagement and engagement volume of all the metrics. The overall engagement consists of metrics like the number of likes, comments, shares, dislikes, views, rewteets or favorites received by a given piece of content (post, video, tweet). The engagement volume is the overall engagement of a given metric (for example the number of likes received by a post) divided by the number of users who subscribed to that account (for example the number of fans on the Facebook page that created that post).

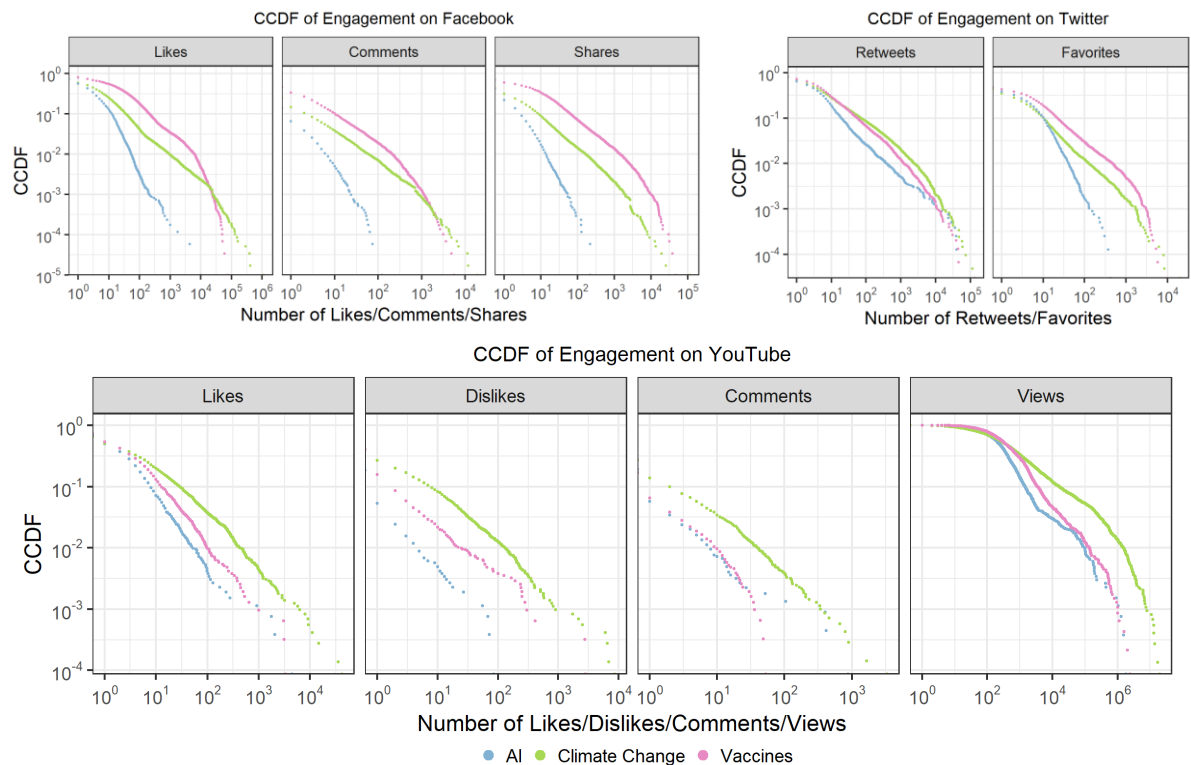


Figure 37 - CCDF of Engagement Metrics on the three Platforms for each Case Study. Shows the probability of a post/tweet/video getting x or more of the given engagement metric.

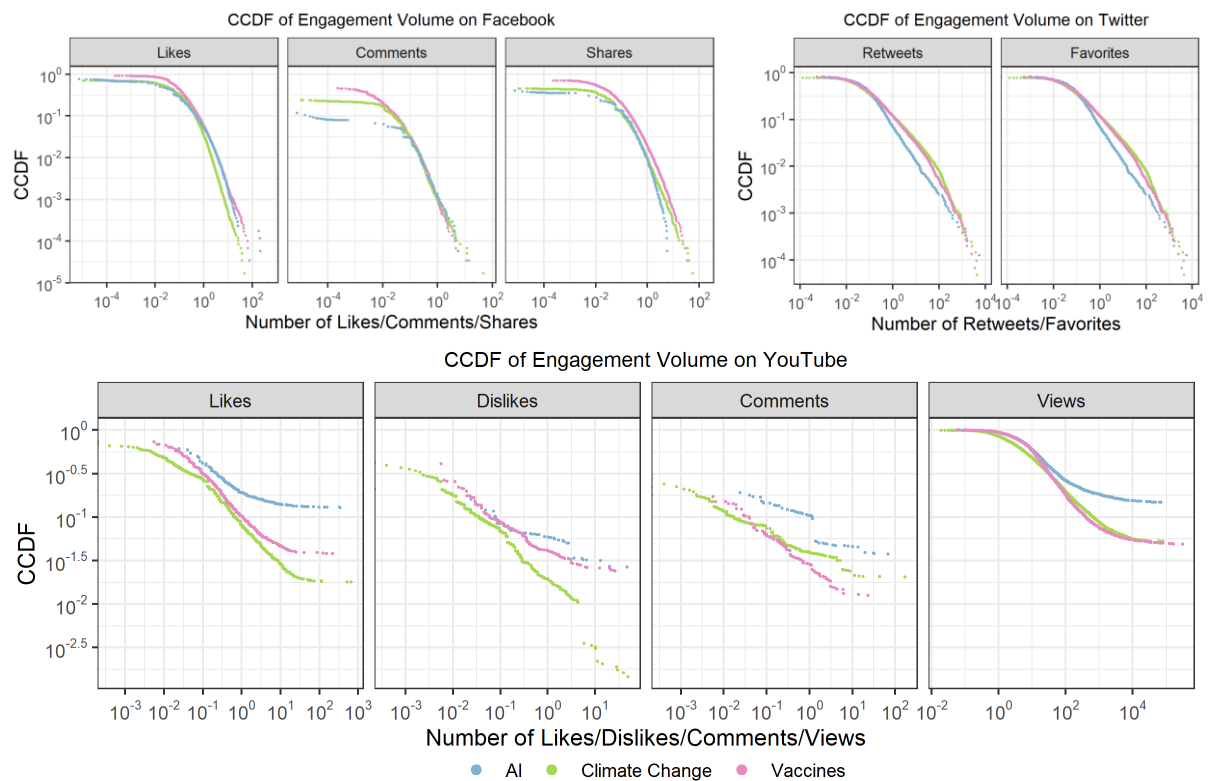


Figure 38 - CCDF of Engagement Volume on Facebook, Twitter and YouTube by Case Study. E.V. was calculated as the number of likes (or retweets, or shares, or views, etc) received by a specific piece of content (post, tweet, video), divided by the number of people who liked the account that published that content (number of fans, followers, subscribers).