“Being Simple on Complex Issues” – An Expert View on Visual Data Communication of Climate Change

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Abstract—Despite overwhelming scientific consensus concerning the threatening impact of climate change, public understanding on the topic seems to lack depth. Data visualizations play a critical role in both communicating scientific evidence about climate change and in stimulating engagement and action. To investigate how visualizations can be better utilized to communicate the complexities of climate change to different audiences, we conducted interviews with 17 experts in the fields of climate change, data visualization, and science communication, as well as with 6 members of the broader citizenry. We use our findings to derive implications and recommendations for creating more effective visualizations, particularly in news media sources geared toward lay audiences. Implications include the establishment of an iterative, user-centered co-design process, the adaption of contents according to the needs of the audience, and the integration of information and formats which users can relate to. We further discuss the role of storytelling, aesthetics, uncertainty representation, and interactive techniques in the visual communication of climate change.

Index Terms—Charts, climate change, general public, guidelines, sense-making, storytelling, uncertainty, understandability

1 Motivation

Despite overwhelming scientific consensus concerning the threatening impact of climate change, public understanding on the topic seems to lack depth. Widely known alarming prognoses on the one hand coexist with limited public engagement on the other hand. A 2021 survey by Pew Research Center [1] found that while the majority of the general public in first world countries is concerned that climate change and its consequences will harm themselves personally in the future, 27% of the respondents claim to be not too, or not at all, concerned. 19% of the respondents state that they will not willingly change their behavior in order to fight climate change. The corporate and political engagement needed to affect change in climate matters may also not be sufficient. The State of Climate Action 2021 Report published by the World Resources Institute [2] states that far-reaching transformations across all sectors and regions are needed to prevent worst-case scenario impacts of global warming, highlighting that “much more could be achieved if all decision makers around the world gave climate action the high priority it is due” [2, p. 3]. One of the reasons for this lack of concern could be a lack of understanding about the scientific evidence of climate change [3]. Climate change is a wicked problem [4], involving complex relationships between environmental and social factors. At the same time, climate change research relies on vast amounts of heterogeneous data [5], [6] which are used to create and test models, often with a high degree of uncertainty attached. The complexity of the topic coupled with the mixture of data, methods, and the use of models make communication to different audiences a challenge.

Even though an extensive part of existing research has focused on climate change communication through textual forms, climate change communication is witnessing a trend toward visual formats in practice and in research [7], [8]. Researchers have investigated the impact of photos [9], films [10], and the role of social media [11], [12] in developing effective forms of communication on the topic. The growing importance of visuals has lead to various ways of visualizing climate matters with the contentious ‘hockey stick’ curve on global temperatures being one of the best-known examples [9], [13]. While climate change imagery is the focus of much research (e.g. [14], [15]), less work focuses specifically on climate change data visualizations, e.g. charts, graphs or maps. As visual representations of data are crucial in communicating the science behind climate change to decision makers and the public [16], the study of how to design climate change data visualizations and how people interpret them is of critical importance.

This study investigates how different experts think visualizations can be better utilized to communicate the complexities of climate change to different audiences. Thereby we explore expert perspectives on how to design climate change data visualizations as well as on how they are interpreted by different audiences. Hence, we address the following two research questions: i. What are common challenges people face when interpreting data visualizations about climate change? ii. How can data visualizations about climate change be designed to support factors such as readability, understandability, and trustworthiness? To seek expert opinions on those research questions, we interviewed 17 participants with expertise in either climate change, data visualization, or science communication. We further interviewed 6 members of the broader citizenry to compare their opinions to the experts’ assessments.

As a discussion prompt in the in-depth interviews, we showed participants two visualizations from online news articles that were released in response to the publication of the Sixth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC) [17]. We also showed them corresponding representations of the same data from this report to compare design choices. The IPCC is the United Nations body for assessing the science related to climate change; it prepares comprehensive scientific reports for policy makers with updates about climate change, its implications, and mitigation options. In addition to being the primary resource for translating climate change science to policy makers, it is also used as the basis for public discourse on the topic [18].
We use findings of the interviews to derive implications for creating more effective visualizations, particularly in news sources geared toward lay audiences. Implications include the establishment of an iterative, user-centered co-design process, the adaption of contents according to the needs of the audience, and the integration of information and formats which users can relate to. This work therefore contributes to the existing literature by providing:

- in-depth expert insights about the role of news sources and data visualizations in climate change communication
- a better understanding of how to cater climate change data visualization to different audiences in light of common difficulties and problem areas
- implications for designing high-quality climate change data visualizations relevant for a range of creators, i.e. educators, policy makers, domain experts, journalists, practitioners and the visualization community.

2 RESEARCH BACKGROUND

A range of stakeholders including climate researchers, environmental organizations and agencies, activists, artists and news media sources are involved in the visual politics of climate change [19]. We review research investigating climate change data visualizations from two common sources: the IPCC and news media outlets.

2.1 Climate Change Data Visualizations by the IPCC

The IPCC publishes regular assessments summarizing the latest science related to climate change. With 195 member countries and thousands of contributing climate scientists and experts, the IPCC is a reliable source of scientific knowledge [20]. Data visualizations, such as charts or graphs, have become an integral part of climate change communication; the IPCC also emphasizes the importance of visualizations for their communication strategy: “graphics form the cornerstone of the information provided by the IPCC” [21] p. 2-04), with line graphs being one of the most common choices of IPCC authors [19]. The importance of visuals in IPCC publications has also been studied scientifically. Pidcock et al. [22] conducted an online survey and semi-structured interviews where they investigated how IPCC authors try to engage non-expert audiences with climate change topics. Among other principles of communication, the respondents named the use of effective visualizations as a key factor in public engagement, with 35% of respondents mentioning IPCC figures and 21% naming scientific data-driven figures as tools to facilitate understanding. 12% of the respondents expressed that there is a need for simplifying IPCC data visualizations to make them accessible to lay audiences.

2.1.1 Simplification vs. Accuracy

The IPCC itself has acknowledged that non-expert readers often struggle to interpret data visualizations correctly [23]. However, creating data visualizations that are both scientifically correct and accessible for non-expert readers is not trivial: “visual science communication on climate change has always been walking a thin line between scientific accuracy on the one hand and reducing complexity for public understanding and engagement on the other” [19] p. 136]. Visualizations typically fulfill a variety of functions including depicting complex facts and simulated projections, providing guidelines to (non-expert) decision makers and conforming to aesthetic principles [19]. Harold et al. [24] conducted interviews with IPCC authors to investigate how IPCC visualizations were created. Results show that the balance between making visuals more accessible and maintaining scientific accuracy is often a challenge. By questioning both IPCC authors and a group of students, it was found that IPCC authors are generally aware of the level of comprehension difficulty in their visuals. Further analysis suggested that higher visualization complexity is associated with greater perceived comprehension difficulty. The authors suggest computational approaches and user testing to tackle the challenge of decreasing complexity while maintaining accuracy.

2.1.2 Understandability for the IPCC’s Target Audience

Other research focuses on identifying how understandable IPCC graphics are for their intended audiences. Fischer et al. [25] examined the objective (accuracy) and subjective (self-assessment) understandability of IPCC visualizations. Respondents included a sample of visitors at the 2016 United Nations Climate Change Conference and a sample of students. With a mean of 0.33 for the conference attendees and 0.38 for the student sample, the presented graphs showed a low objective understandability. The self-assessment of respondents from the conference sample was increasingly inaccurate, meaning they were wrong about assessing which graphs they interpreted correctly. Fischer et al. [26] evaluated graph comprehension among decision makers from 54 countries and junior diplomats from Germany by using two IPCC graphs, which either employed or violated principles of intuitive design. Findings reveal that the counter-intuitive visualization was systematically misinterpreted, while the intuitive one was mostly interpreted correctly. McMahon et al. [27] investigated one particular IPCC visualization, namely the scenario graph depicting the global surface temperature development for the 21st century according to simulated emission scenarios. Interviews with representatives of the IPCC’s Summary for Policymakers’ target audience were used to test how people perceive the uncertainties displayed in this graph/its caption. Participants had difficulties identifying the types of uncertainty present in the visualization. The authors suggest that design choices highly influence how readers perceive the graph and interpret its scientific message.

2.1.3 Creating Effective IPCC Visuals

Scholars have also investigated how IPCC data visualizations should be created to make them understandable and hence most effective. Harold et al. [28] introduce four key pillars that IPCC authors should consider to create clear and accessible data visualizations: message, audience, design, and evaluation. First, IPCC authors should identify a clear message for the visual to express. While assessing the target audience’s prior knowledge is essential for incorporating their needs into the visual, using design formats the audience is familiar with helps the readers with understanding. Finally, visualizations should be tested by members of the target audience and revised accordingly. The IPCC’s increased engagement with creating more effective visuals seems to have already paid off: while IPCC graphics have been criticized for being inaccessible for non-specialists [29], the reactions to the visuals presented in the “Climate Change 2021: the Physical Science Basis” report were much more positive [30]. Climate scientist Ed Hawkins wrote: “One key development since AR5 was the involvement of professional graphic designers in creating the figures for the Summary for Policymakers (SPM). As a result, the graphics are clear and usable, having been user-tested through several design iterations” [31].
2.2 Climate Change Data Visualizations in News Media

News media outlets also play an important role in communicating climate change to the public. In a longitudinal analysis of climate change imagery in print media sources, O’Neill [15] examined over a thousand images published in UK and US newspapers between 2001 and 2009. Results show that visualizations of climate change topics experienced a rapid increase after the year of 2005. It was also found that scientific data visualizations, like charts or maps, were fairly uncommon during that time. Other analyses of the design spaces of climate change data visualizations [32, 33] do not focus solely on news media sources. Research on climate change visualizations in news sources focuses on the content or the public perception of climate change visualizations. The former studies the themes and frames of climate change imagery in popular news sources (e.g. [15, 34–38]), the latter focuses on the public perception of climate change visuals and peoples’ engagement with them (e.g. [39–46]). Most of the research addresses the use of imagery in general and lacks a clear distinction of data visualizations such as graphs or charts.

Besides this focus on imagery, not much is known about the understandability of climate change data visualizations used in news formats. Analyses that investigate the understandability of graphs, charts, or maps about climate change often use visualizations published by the IPCC, rather than visualizations that can be found in commonly used news sources. Studies with a clear focus on climate change data visualizations from different sources and for different audiences are still scarce.

3 Methodology

To investigate how data visualizations can be better utilized to communicate the complexities of climate change to different audiences, we conducted interviews with experts in the fields of climate change, data visualization, and science communication, as well as with members of the broader citizenry. The following sections explain the research focus and methodology choices.

3.1 Research Focus and Questions

With IPCC materials being used as the basis for the public discourse on climate change [18], it is not surprising that many studies focus on IPCC content. However, the observation that analyses testing the understandability of climate change data visualizations commonly use IPCC figures instead of visuals from news sources leads to the question if data visualizations about climate change in news media sources are in fact different from the ones published by the IPCC. To gain insights on how news sources report on IPCC publications as a major event in climate change communication, we investigated 85 of the most popular online news sources from the UK, the USA, and Germany for articles that were released in response to the Working Group I contribution to the IPCC’s Sixth Assessment Report “Climate Change 2021: The Physical Science Basis” (AR6-WGI). In this investigation which we conducted in November 2021, articles were retrieved through a Google search. A detailed rationale behind the selection of news sources and article selection criteria can be found in the supplementary material.

132 articles met our selection criteria and were further examined for data visualizations. While the Summary for Policy Makers (SPM) of the AR6-WGI includes ten central data visualizations, five of those were rarely depicted in news media sources and the other five were more heavily used. In total, our online newspaper sample contained 47 data visualizations from which 34 were modified or recreated versions of the IPCC originals. We conclude that even for this sample consisting only of direct reports about an IPCC publication, there were more recreations/modified versions of IPCC visualizations in newspaper sources than direct copies. Considering that studies with a clear focus on the understandability and design of climate change data visualizations from different sources are still scarce, we identify a need for investigations that use data visualizations from popular news media sources.

By using newspaper representations of climate change data visualizations as discussion prompts in interviews with members of groups that commonly create climate change data visualizations, this study aims at establishing a better understanding of experts’ perceptions on how data visualizations can be created to meet the needs of different audiences. Research question RQ-1 accounts for the reader’s perspective, addressing questions like how climate change visualizations from different sources are understood by different audiences and what the perceived reader’s needs are. Research question RQ-2 was formulated to represent the creator’s point of view and how data visualizations can be designed and used in different channels to address the needs of different audiences.

1) Reader’s perspective (RQ-1): What are common challenges people face when interpreting data visualizations about climate change?

2) Creator’s perspective (RQ-2): How can data visualizations about climate change be designed to support factors such as readability, understandability, and trustworthiness?

3.2 Expert Interview Study

With the goal of seeking expert opinions on those research questions, we opted for an expert interview study for the following reasons: Experts are potentially involved in the creation of climate change data visualizations and not only have experience in and opinions about their design, but they also have an interest in outreach and creating understandable visuals. Besides that, experts are also readers themselves, who see visualizations on a regular basis. While expertise could be received as a limitation when making implications for lay audiences, a previous study found that experts are aware of their audience’s needs [24]. We choose this qualitative approach over quantitative methods to gather in depth insights into this area, as well as to identify themes that were not necessarily included in the research focus but might still be of importance. Semi-structured interviews are an established method to collect data about complex phenomena and are structured “around a set of predetermined open-ended questions, with other questions emerging from the dialogue” [47]. We decided to do a single round of research and individual instead of group interviews to get unbiased opinions from different perspectives.

Most studies investigating climate change data visualizations derive design implications from interviewing/surveying IPCC authors and typical readers of IPCC reports, like policy makers or climate conference attendees (e.g. [22, 23–27]). Contrary to previous analyses, we aim to study different perspectives on this topic with a particular focus on persons who engage in public discourse. Climate change is a complex topic and creating data visualizations that are accurate and understandable is a problem that can only be tackled by involving different stakeholders. By combining and comparing different perspectives on a topic and different types of expertise, we explore “different ways of knowing”, how particular views might dissent or coincide, and how they can
be put together to inform the creation of climate change data visualizations. Experts were therefore selected according to their affiliation with one of the following fields of expertise: climate change (CC), data visualization (VIS), science communication (SC). While previous studies that engage with experts specifically focused on IPCC authors, we expand our sample to CC experts in general (not limited to IPCC authors). Thereby, we also account for opinions from CC experts, which do not have any stake in IPCC publications and might be potentially less biased. We also include VIS and SC experts in our analysis, as VIS experts bring expertise on what works technically and in terms of perception and SC experts have insights on how lay audiences can be reached.

### 3.3 Participants

We used purposive sampling within an expert network to contact participants. Besides their expertise in either CC, VIS, or SC, all included participants are international experts and known scientists, who are experienced in their field and at an advanced stage in their career. Experts with a scientific background regularly publish in peer-reviewed journals. Further inclusion criteria included a proficient level of the English language, diversity factors, and the willingness to engage in a recorded interview. A total of 17 experts from Europe and North America were interviewed, from which 6 had a CC, 5 a VIS, and 6 a SC background. In terms of the number of interview participants, we exceed the threshold at which data saturation normally occurs [48], [49]. As can be seen in [Table 1](#), experts’ job roles and research areas/disciplines span a number of different areas. Interviewees were asked about their expertise in the other fields, e.g. CC experts were asked to rate their experience in SC and VIS on a scale from 1 (very low) to 10 (very high). [Table 2](#) shows an overview of the median values within each expert group. To compare the results of the expert interviews with opinions and viewpoints from lay people, we interviewed 6 members of the broader citizenry (BC) with an adapted interview schedule. Participants were selected on the basis of diversity factors (age, gender, education, occupation). [Table 3](#) shows the participants’ self-reported job roles and highest level of education. Participant’s age ranges can be seen in [Figure 1](#). Interviewees received no compensation for their participation. The study was approved by the University of Vienna’s ethics committee.

### 3.4 Interview Procedure and Schedule

In semi-structured interviews participants were asked to share their opinions about climate change data visualizations. Questions were intentionally formulated broad and open-ended, as they were intended to serve as discussion prompts to identify aspects that are regarded as important by the experts. Further questions were included on the basis of the individual discussion focus. Rating questions, asking participants to evaluate specific aspects on a scale, were used to get a sense of their assessment. Expert interviews were conducted and recorded online via Zoom; BC interviews were mainly held in-person according to the participants’ preferences.

Two pairs of climate change data visualizations were used as a basis for discussion about aspects like quality, understandability, or trustworthiness. The example visuals were selected from the sample of news media representations of IPCC graphics (discussed in [subsection 3.1](#)). The supplementary material provides an overview of how often copies or recreations/modifications of the ten figures in the SPM-AR6-WGI were included in 132 investigated online articles. We picked two visualizations of the ones that were most often modified/recreated as example visualizations for the interviews. For BC participants, we provided the visualizations in...
their native tongue. After a discussion of the respective news media representation, also the original visualization from the IPCC report was shown to the participants to make comparisons on specific design choices. If the news media version depicted only a part of the original, this was stated clearly in the interviews and a zoomed-in version of the IPCC visual, depicting the same fraction of data, was provided. Figure 2 (recreation by BBC News at bbc.co.uk/news [50]) and Figure 3 (original by the IPCC [17]) show the first pair of example visualizations. All used visualizations and details about the selection process can be found in the supplementary material.

The interviews took 30-60 minutes each and followed a set structure, with some questions being only posed to a specific group (details can be found in the supplementary material): (i) Introduction & consent. (ii) Demographics: Data about the participants’ job role, age, etc. was collected. (iii) Climate change: CC experts were asked about their opinion concerning climate change awareness/understanding among the public and actions taken by companies and governments. BC participants were asked about their interest in climate change and their assessment about the actions taken to fight climate change. (iv) Climate change data visualizations: Experts and BC participants were asked about their opinion concerning the benefits/drawbacks of using data visualizations for communicating climate change topics, their understandability, and common interpretation difficulties. (v) Example visualizations: Depending on time, either one or two pairs of example visualizations were shown to the participants as a discussion basis. Questions included aspects of understandability, improvement potential and personal preference concerning design choices of the original vs. the newspaper version.

The interview recordings were transcribed and analyzed thematically using the qualitative data analysis software Atlas.ti. Codes were created by systematically going through the interview transcriptions employing a combination of deductive and inductive thematic analysis [51]. Deductive codes were oriented on the interview schedule, informed by literature (e.g. concerning understandability or uncertainty representations [25, 27]). The analysis was performed by the main author of the paper, who created an initial code-book with supporting examples. To enhance the reliability of the coding scheme, three senior researchers checked and discussed the code-book for a sample of the data iteratively until consensus was reached. A nested coding tree with a total of 5 code groups, 50 primary and 303 child codes was reached. The interviews were analyzed a second time by the main author to ensure correct assignment. Codes were structured according to groups (demographics, climate change, data visualization, example visualization pair 1 and 2) and aggregated into broader themes, which are used to structure the findings.

4 Results

The results are structured according to three major themes: public climate change communication including the role of news sources and data visualizations (findings beyond the posed research questions), common perceived challenges for readers (RQ-1), and implications for creating understandable climate change data visualizations (RQ-2). Findings represent a summary of experts’ statements, which are compared to opinions from participants from the broader citizenry, if applicable. Quotes and selected findings are listed with a pseudonym indicating group affiliation: CC for climate change, VIS for data visualization, SC for science communication experts, and BC for members of the broader citizenry. Implications were drawn from interviewees’ general assessments, or from comments in respect to the example figures (marked as such). A full list of results can be found in the supplementary material. While our implications may seem common/similar to other work, our results add nuance from different perspectives and tease out what this looks like for climate change in particular.

4.1 Public Climate Change Communication

In the course of the interviews, CC experts named public climate change communication as one of the most urgent topics of the moment. This section summarizes the main findings in terms of climate change communication to the public in general and facilitated through data visualizations in specific.

We Need to Act. According to CC experts, extreme weather events, migration, and changes concerning the economic/health situation count among the main consequences of climate change. The inequalities of those impacts were also apparent: while interviewees mentioned that the consequences highly depend on the region, they also claimed that socially weaker groups will be affected worse. CC experts were asked what they think are the most important messages people need to understand about climate change. The answers give a sense of the urgency of the issue: we need to act now; everybody can do something; or substantial changes are necessary are some of the mentioned messages.

“We need swift action and we need massive action. If we hesitate to act now, and that’s actually what’s happening, then the burden for the next generations [...] will be extremely hard.” – CC-5

4 of the 6 CC experts rated the efforts of companies and governments to address climate change on a scale from 1 (very low) to 10 (very high) below or equal to 5. BC participants were asked about their assessment of the efforts to react to climate change in general (also including private persons). While all BC
participants acknowledged that not enough is done, but all but one rated the efforts below or equal to 5. BC participants expressed their anger toward the government for their lack of action (which is perceived as more important than private action), but also toward the unequal distribution of efforts among countries. “It’s already urgent since 50 years, and we’re still not doing a lot. Or we pretend to do something, but it’s not enough.” – BC-1

As opportunities for improvement, CC and BC participants mentioned the necessity of government-appointed regulations, as well as actions individuals can take to reduce their impact such as stopping to eat meat or using climate-friendly transportation alternatives. According to CC and BC participants, reasons for the lack of action include cost-factors, political reasons like lower chances in elections or the association with lobbyists, the lack of willingness to reduce personal freedom, as well as a lack of understanding, especially in private contexts. Some BC participants claimed that climate change is not a present topic for younger generations and that people believe that climate change is not real.

**News Media Sources Play a Pivotal Role.** All but one CC expert rated the awareness/understanding among the public concerning climate change and its consequences below or equal to 5, on a scale from 1 (low) to 10 (high). Experts also differentiated between awareness and understanding, rating awareness higher than understanding. In comparison, all BC participants claimed that climate change is something they think about a lot, with reasons spanning the perceived urgency and affectedness, anger towards politics and regulations, and the reporting about global warming and nature catastrophes in news media sources. BC participants also suggested that climate change topics are not covered in enough in sources they use, especially when it comes to topics fostering the understanding of climate change.

“I wish there was more information. […] I think there isn’t enough education about it unless you actively look for it.” – BC-2

We asked CC experts “What academic journals or also non-academic media outlets for the general public do you think are important in the context of climate change?” Even though the question was not aimed at an comparison concerning importance, experts mentioned the irrelevance of scientific sources for the general public. Participants emphasized the essential role of news media and social media for the public discourse about climate change, as well as the importance of training journalists in science communication and securing science communication funding.

“A.Aademic journals [are] almost not important at all for communicating with the public. […] The IPCC report is extremely helpful, but not because people read it, but because it gives weight.” – CC-3

BC participants reported to use television, radio, online/print newspapers, and social media apps as sources to obtain information. Some BC participants expressed that they either do not use classical news sources such as newspapers, or suspect other people to not do so, and suggested to address climate change topics also in sources like popular leisure magazines or social media.

**Data Visualizations as a Means to Foster Understanding.** Participants acknowledged the necessity and benefits of visual communication: 11 experts and all BC participants stated that they would first look at a data visualization in a news article about climate change before reading the text. Some BC participants further claimed that they would not read the text, if they do not like the visual or that they would not read the text in either case, but might have a look at the visualization. 8 experts and 4 BC participants think that common news sources should make more use of data visualizations when reporting on climate change.

“Data visualization is key for people to raise awareness.” – CC-5

Benefits of communicating climate change through data visualizations were acknowledged by all expert groups and BC interviewees; their reasoning can be summarized as follows: **Attention & engagement:** Data visualizations are said to do well in catching and keeping the user’s attention. **Visual preference:** According to the interviewees many people show a general preference toward visual formats. **Complexity reduction & understandability:** CC, SC and BC participants argued that data visualizations can reduce a topic’s complexity and increase understandability. BC participants mentioned that it is often easier for them to understand a visual than text with technical terminology. **Possibilities to show data:** VIS and SC participants mentioned that data visualizations can also enable the creator to show high amounts and complex data.

“For many people visuals are just much faster to understand than if they had to read a page of text.” – BC-5

Interviewees were also asked about the drawbacks of data visualizations in climate change communication. While several issues were mentioned that need to be considered, these did not speak against the usage. Experts and BC participants expressed their concern about visualizations being used to intentionally manipulate, but this is also a problem with text. A factor that could be considered as a real drawback of data visualizations compared to text is their lower accessibility for visually impaired persons.

**The Importance of Data Visualization Quality.** During the interviews experts stressed the importance of quality of climate change data visualizations. Even to catch their first attention, SC experts explained that they would be more likely to look at a well-done visualization compared to a badly designed one. Experts mentioned that the quality of data visualizations highly depends on the publishing medium, with some high-quality newspapers creating excellent visuals and other less sophisticated ones showing a significant drop in quality. The assessment whether a visualization is well-designed or not also strongly depends on the visualization’s purpose, outlet, or audience: while a data visualization could be very appropriate for a scientific source, it can be a bad choice for a newspaper article, and the other way around.

“And sometimes I argue to students, there’s not a good or a bad visualization. It really depends on the purpose you have.” – VIS-4

It seems to be undisputed that creating high-quality data visualizations is not a trivial task: design choices might unintentionally result in ambiguous/misleading visualizations or finally readers misinterpreting the message. Experts argued that creating effective data visualizations can and should be taught. While some participants think that there have been improvements in the last years in university education, the majority of participants is convinced that current university curricula from various fields could be improved by adding visualization courses.

“It’s very hard to create a graphic that is unambiguous in its message. Can be done, but requires work. […] It’s a technical issue and thus can be taught. And we don’t do that.” – CC-1

Without being directly asked about it, the importance of quality of a visualization was mentioned by participants among all expert groups, with SC experts stressing quality issues most often. The need for more data visualization education was acknowledged by a majority of the participants over all expert groups.
4.2 Readers’ Perspective (RQ-1): Common Challenges

Independent of the example visualizations that were shown to the interviewees, this question was posed to all participants: “Would you say it is rather easy or difficult for people to interpret visualizations about climate change correctly?” While 2 experts and 1 BC interviewee thought that it should be easy for anyone, 13 experts and 4 BC participants claimed that it would be difficult, especially for people with no prior knowledge in climate change or data visualization. The opinions about the understandability of [Figure 2] were quite diverse: while 9 experts and 2 BC participants claimed that it should be easy for anyone to interpret the figure, 6 experts and 4 BC interviewees thought this would be difficult. To get a sense of what makes a visualization understandable, this section discusses results in regard to RQ-1, which was aimed at identifying common perceived challenges for readers when interpreting climate change data visualizations.

Climate Change Is Complex. BC participants named insufficient understanding due to the complexity of climate change as one of the main causes for the lack of climate action. Complexity was also mentioned by BC participants as a major factor why interpreting climate change data visualizations can be difficult.

“It’s just a very complex topic. And unless you’re willing to spend serious time on thinking about it, I believe it’s just hard.” – CC-1

When it comes to climate change, background knowledge about the concepts and data seems to not be a given for a lot of people: A lack of education or socialization in regards to climate change was mentioned as one of the main climate change topics currently, as well as a reason for low ratings of understanding among the public.

“We should start from the kindergarten throughout the whole educational path, to build into the curricula, at whatever level, at whatever discipline, also sustainability related issues.” – CC-2

Due to the complexity of the topic and limited attention spans, experts acknowledged that a deep understanding among the public might not be a realistic goal and it is more the trust in science that gets lay people to grasp the urgency of climate change.

“You have to trust science, which is very close to believing in something, because you cannot reproduce that knowledge.” – SC-4

Findings suggest that the lack of understanding can be partially attributed to the complexity of the topic. Without being asked, both the lack of understanding and the complexity of the topic was also mentioned by non-climate experts.

Interpreting Data Visualizations Is Difficult. The majority of participants thought that interpreting data visualizations requires different kinds of background knowledge. Participants mentioned the lack of visual data literacy among the public as a problem. Areas of education that should be emphasized include mathematics (like graphs and scales), visualization knowledge (like visualization types), and basics about predictions and uncertainty.

“One mistake we in the visualization community make is that we overestimate the visual literacy of people.” – VIS-4

Experts and BC participants shared their opinions about common difficulties with data visualizations and named uncommon visualization types as one of the main factors that hinder understanding. While BC participants frequently commented on the use of color, VIS and SC experts mentioned that colors can be the cause of misinterpretation. Experts and BC interviewees thought that predictions in general, uncertainties in visualizations, as well as scales/axes in graphs are difficult for lay users to understand.

“In future it should be normal to have this uncertainty included, but then you have to teach this […] what is a prediction about, what is the confidence interval […], nobody knows this.” – SC-1

While the increased understandability of data visualizations compared to text was mentioned as one of the main benefits by experts and BC participants, experts also named misinterpretation as one of the most important problems. A possible solution could lie in emphasizing those issues in school education.

Attention Is More Important Than Understanding The question whether [Figure 2] would be easy or difficult to interpret, was answered by a BC participant with the comment that the first concern when communicating to the public should be whether a visualization is attractive enough to catch the readers’ attention. We asked BC participants if the newspaper versions of the example visualizations would catch their attention, if they saw it in their everyday news sources. For [Figure 2], 4 of the 6 BC interviewees acknowledged that it would not catch their attention.

“The main problem is: Would you actually look at it?” – BC-1

CC/SC experts and BC participants have mentioned the lack of attention or missing time/involvement on the readers’ side as one of the main problems in visual data communication. Ways to create a climate change visual that is understandable and attractive are discussed in the next section.

4.3 Creators’ Perspective (RQ-2): Design Implications

Participants shared their opinions on what makes a high-quality visual for them and made recommendations on how to create effective climate change data visualizations (RQ-2). We summarized the findings under three main themes: Embrace the process and the audience; make it simple, but transparent; and make it attractive.

Embrace the Process and the Audience. Experts claimed that the design process of a data visualization has a substantial influence on its resulting quality: mentioned factors included co-design, iterative design, and framework conditions like time, funding and expertise. While the communication between domain and visualization experts was named as a challenge, an iterative co-design process was described as the collaboration between climate change scientists and visualization experts that starts with the purpose of a visual and passes through several design iterations.

“We can overcome all these problems, if we design in the right way, if we co-design, if we have a human-centered approach.” – SC-6

An iterative design process was also mentioned in the context of user testing and creating data visualizations in a way that makes them understandable for their intended target audience: adapting climate change data visualizations to the knowledge and needs of the users was named by VIS and SC experts as an aspect of how to influence the quality of data visualizations. VIS and SC experts also named the optimization in respect to the used publication channel as an important aspect for creating high-quality data visualizations.

“Embrace the audience in the design process to make sure that you understand how they interpret the information.” – SC-6

Participants have also emphasized that relatability to the contents of a data visualization plays a big role in getting and keeping the readers’ attention. While VIS/SC experts have mentioned creating relatable climate change visuals as a general recommendation, they have also criticized [Figure 2] for not showing any consequences readers can relate to. Visualization types were mentioned as a means to increase relatability, e.g. by choosing maps...
to show the consequences for specific regions. BC participants claimed that climate change content that focuses on the future, showing consequences or solution strategies are most relatable. 2 BC participants spoke against the depiction of “horror scenarios”. Climate change experts named emotions and responsibility as two of the main climate change topics currently.

“You really have to make sure that people can relate with whatever you communicate [...] which is definitely difficult when it comes to climate change, because it’s a very abstract thing.” – SC-4

Even though the complexity of climate change was widely acknowledged among CC experts, the adaption of visuals to the target audience’s needs was mainly mentioned as a quality factor by SC and VIS experts and BC participants. Particularly VIS experts, as well as BC participants have stressed the importance of depicting contents, which are relatable for the intended target audience, as a means to capture and keep the readers’ attention.

**Make it Simple, but Transparent.** Participants have mentioned that people’s ability to interpret data visualizations about climate change heavily depends on the visualization design, whereby some speak in favor of designing visuals in a way that makes them accessible to anybody. Participants among all expert groups as well as all BC participants named simplicity and complexity reduction as key factors in creating effective data visualizations.

“If the visualization is done very good, it should be super easy to understand it. And that’s the problem with most visualizations [...] most visualizations are still too complex.” – CC-5

The simplifications made in Figure 2 compared to Figure 3 were mentioned as positive criticism by 3 experts and 2 BC participants; 4 experts and 3 BC participants thought that it was still too complicated, e.g. due to wording or the visualization type.

“It is still this science graph style, with y axis, x axis and so on. This would not be the type of data visualization I would envision for the broader public. It is too complex.” – CC-5 (about Figure 2)

As a factor that positively influences visualization quality, experts mentioned the definition of a clear main message or intent, story telling techniques, as well as the effective combination of visualization and text. When presented with Figure 2, 7 experts and 3 BC interviewees felt that the creator of this visualization did a good job in depicting the main message, while 8 experts and 1 BC participant regarded the visualization as mediocre and 1 VIS expert and 2 BC participants as bad in terms of a clear message.

“If you don’t know what the intent is, [...] there’s no way you can ever do a good graphic, except by complete accident.” – CC-1

It is not only important that a distinct story is told, but also that it is told in a way that makes it understandable for the audience. In regard to Figure 2 opinions were divided: while some experts and BC participants spoke in favor of the title and the annotations, interviewees from all expert/BC groups criticized that the used wording is too complicated for a news source. Experts and BC participants expressed that they would either have liked further annotations for the lines that are just summarized or thought that it would be something that is hard for the general public and hence preferred Figure 1. BC participant spoke in favor of including uncertainty ranges, as it would ease the public’s concern (despite the deviations in both directions).

“I don’t see an added benefit of putting that burden of uncertainty onto the [general public] because it doesn’t make a huge difference for the main message.” – VIS-3

The issue of simplification vs. accuracy was discussed throughout the expert interviews, with one participant naming “being simple on complex issues” as one of the most complex challenges. While some experts regarded over-simplification as a problem, simplification was named as an important quality factor for understandable data visualizations, both by experts and BC participants. Factors that support this need include the complexity of climate change and missing time and involvement on the reader’s side.

“The risk you run, if you insist on scientific rigor [...] is that you might lose your audience altogether. And then you’re not conveying the depth of your message either.” – CC-1

The need for simplification was an apparent theme among all expert groups, with SC experts being more set on maintaining scientific accuracy than others. BC participants spoke in favor of depicting climate change contents as simply as possible and suggested that no background knowledge should be assumed.

**Make it Attractive.** Besides contents, also aspects of good design and aesthetics matter: while the amount of information should not overload the visualization, contents should be presented in a clear manner. CC/VIS experts mentioned guiding user perception through positioning and highlighting of important information. Info-graphics were mentioned by VIS, SC and BC participants as a way to engage the general public in complex topics. By using color, pictures or icons, the attention of readers who are not particularly interested in climate change could be gained.

“If you’re communicating to the general public, there’s this stuff you can do. [...] To actually add graphical depictions around, to add more color, to add memorable context. [...] It attracts people in the first place. And that’s what you want, right?” – VIS-1

2 SC experts and 1 BC participant criticized Figure 2 for its lack of pictures/icons that would make it more appealing for the general public. Some interviewees expressed that Figure 2 appears to be cluttered, suggesting a reduction of text or different positioning of the annotations. Finally, participants had different opinions concerning the line coloring in Figure 2. While 7 experts and 3 BC interviewees felt that the colors seem random and would have liked a blue-to-red color scale like in Figure 3, 3 VIS experts spoke in favor of the categorical colors, as they are easily distinguishable.

“Colors – totally random. Strange that they use purple twice, light and dark purple. I expect some ordering here.” – VIS-4
BC participants were asked about the perceived trustworthiness of the example visualizations and the answers give a sense of the importance of design choices. While 3 participants did not have a preference concerning the figure, 2 found the IPCC representation to be more trustworthy. Another participant stated that both of the figures are not trustworthy, as they are both not understandable. While the missing degree symbol in [Figure 2] was mentioned by experts and BC participants, one BC participant named this as a reason why s/he would not trust this visualization. The second news visualization (details in the supplementary material) was perceived as more attention-getting, mainly because of the coloring: 4 of the 6 BC participants claimed that it would catch their attention. 1 BC participant perceived the scales to be manipulative and hence the figure as not trustworthy, even though it was similar to the IPCC version.

“The scientific graphic is true to scale [...], which is not the case for [Figure 2]. It was stretched insanely: the good part from the old days and the bad part, for which we are responsible.” – BC-5

Participants stated that interactive visualization techniques can be a powerful way to engage users in climate change data. While interactivity can be suitable for specific purposes, e.g. for historical data, participants argued that creators should only make use of it, if users need it. Mentioned benefits and drawbacks include: increased engagement (possibility to explore data by “playing around”); increased relatedness (users can pose their own questions); limited accessibility (they are only accessible to younger generations that have the means); limited engagement (after trying out some functionalities, users’ interest can drop, hence not using the tool’s full potential). While BC participants confirmed the relatability benefits, no one of them has ever used such a tool.

“Interactivity has to be a consequence of [the user’s] needs. It’s not just something that we decide to do because it’s cool.” – SC-6

Principles of good design and aesthetics were mentioned by participants from all three expert groups. VIS, SC and BC participants spoke in favor of using info-graphics as an effective tool to communicate climate change to lay audiences.

5  DISCUSSION

The results suggest that design principles for climate change visuals heavily depend on the visualization’s purpose and audience. With previous studies in the field mainly using IPCC visualizations, our study provides insights into which factors are important in formats for the general public. Hereby, we build on and validate past work about climate change data visualizations, but we also extend it as we i) focus on news sources and ii) combine perspectives from experts in different topics and members of the broader citizenry. Our study shows how different experts emphasize different aspects and have different beliefs and opinions (e.g. about showing uncertainty or not in visualizations for the public or about the level of necessary simplifications). This is partially a factor of their own expertise and experience; it also highlights the contextual nature of understanding data visualizations (e.g. [53]). This section summarizes the interviews’ most prevalent topics and compares the findings to existing literature.

5.1 Attention and Understandability

While our research questions focused on aspects of understandability, experts as well as members of the broader citizenry have stressed the importance of getting the readers’ attention in public climate change communication. In the following, design implications are discussed along those two dimensions.

Getting the Readers’ Attention. Our findings suggest that the willingness to look at a visualization is influenced by its design: while different channels impose different requirements, factors like visualization type, complexity, clarity of the main message, and design details can be used to make a visualization attractive for a specific audience. Similar points have also been emphasized by prior work, e.g. by Harold et al. [28] who give recommendations to IPCC researchers for creating effective data visuals. However, design practices are highly dependent on the publishing medium and the audience, imposing different implications for news media sources than for IPCC material. According to the interviews, noticeable colors plays a major role in getting the readers’ attention, but bold usage of color, font and positioning can also contribute to lower perceived trustworthiness in climate change visualizations. Especially with such an emotionally loaded topic, dramatic design seems to increase attention on the one hand, but can have negative effects in terms of trustworthiness, as readers might feel manipulated. Hence, design choices have to be carefully balanced.

Participants further mentioned infographics as a tool to catch the public’s interest for climate change. Experts as well as BC participants acknowledged the benefits of incorporating images and icons into climate change data visuals, primarily in regard to getting peoples attention, as they appear more interesting and understandable. While there is mixed evidence about their effectiveness in terms of users memorizing the shown data, previous research has shown that infographics can increase user engagement and aesthetic value, as well as memory of the visual itself [53].

Similarly to Corner et al.’s [23] principles for public engagement (e.g. “Connect with what matters to your audience”), our findings suggest that another factor in motivating the users to engage with a visual lies in the relatability of the contents. Participants have mentioned that establishing a connectedness between users’ concerns and shown data can increase interest (e.g. showing concrete consequences of climate change on a map on which the reader can see his/her hometown, or showing photographs). Previous research has shown that local (instead of global) message framing is also most effective in encouraging action [55]. The role of affective communication, incorporating emotional elements into the presentation of data and risk has been researched before as a way to encourage engagement ( [56], [57]). Also creative approaches towards raising climate change awareness, like an art installation depicting concrete consequences of climate change and the public’s emotions toward them, have emphasized the importance of relatability and emotional connectedness [58].

Ensuring Understandability. In order to foster climate change awareness and understanding among the public, data visualizations have to be created in a way that meets the readers’ needs. Understanding data visualizations is a multi-level process with various metrics in place to measure understanding [53]. Previous research has shown that the ability to understand climate change data visuals is influenced by the readers’ background: demographics like age, education, numeracy/graph literacy, and prior belief systems have been shown to influence reading accuracy [59], [60]. Hence, these factors should be taken into account when creating data visualizations about climate change (e.g. [23], [28], [61]) and user-centered design approaches could be used to “ensure the creation of tailored visualisations” [61, p. 315]. Our findings
suggest that three major factors should be taken into account: the reader’s background knowledge in terms of climate change, data visualizations in general, and uncertainty representations.

Major points of criticism regarding the example visualizations have been the perceived complexity in general, as well as too complex wording. Identifying the audience’s prior knowledge and beliefs about climate change can help visualization designers to determine an appropriate depth of the contents as well as to select understandable terminology. While the reduction of complexity for climate change visuals for the public was recommended previously [29], also the usage of simple captions and known terminology was shown to have a positive impact on readers’ understanding [62].

In addition to knowledge about climate change, our findings suggest that the audience’s familiarity with visualization types plays an important role in communicating to the public. Identifying visualization types that the audience is confident with can help increase understandability. This is in accordance with previous work, which found that the type of visualization has a significant impact on how non-expert viewers perceive visuals [63] and that readers prefer graph formats with which they are most confident (e.g. [54], [64]). While interactive climate change visualizations are known to be beneficial in aspects like drawing and maintaining the users’ interest [65], we need to consider that not everyone has the ability or the means to use them.

Our results further indicate that the decision to include or exclude details about uncertainty strongly depends on the readers’ previous knowledge. While the difficulty of understanding uncertainty in public climate change communication was also acknowledged previously [29] and different aspects have been studied (e.g. [62], [66], [67]), we recommend to adapt the uncertainty in a visual to the readers’ prior knowledge (e.g. not show uncertainty ranges in the visual and provide explanations about it in the accompanying text). Especially when thinking about non-expert audiences the potential diversity of readers stands out, which might be an incentive to focus on adaptable visualizations (in an online context) or visual storytelling that builds up complexity step by step, allowing people to stop engaging when they see fit – as can be seen in the work of some practitioners.

Tension between Simplicity and Accuracy Finding methods “to convey information to a broader public in a way that it is simple, but [...] scientifically sound [...] is one of the biggest challenges” (CC-2). With the complexity of climate change as a topic being uncontested, the need for complexity reduction in visuals has been claimed previously (e.g. [29]) as well as by our interviewees. Especially BC participants have mentioned aspects of simplicity both in the context of understandability, as well as for attracting their attention in the first place. Our findings suggest that substantial simplifications in visualizations for the public, e.g. compared to IPCC visualizations, are important and necessary to meet the needs of diverse audiences. However, visualization designers have to be transparent about them in order to avoid oversimplifying contents and potentially loosing the reader’s trust. In this regard, text can play an important role: when a data visualization excludes some information for the sake of simplicity, interviewees suggested that an accompanying text could bridge the gap between simplification and accuracy, e.g. by making the reader aware of details that are not depicted in the visual. How do we design climate change data visualizations that address both the need for scientific accuracy and the needs of diverse users? Literature as well as our findings indicate that a highly iterative, user-centered co-design process, including domain and visualization experts as well as user-testing is the way forward [61], [68]. While such approaches have been in place for IPCC visualizations [68] and included in their recommendations [28], our findings suggest that these practices might also be beneficial for designing climate change data visualizations for common news sources.

5.2 A Complex, Urgent, and Inconvenient Message

In many cases our results show parallels to general principles of science communication (e.g. [69]) and principles of visual data communication (e.g. [54]). However, what makes climate change stand out is the complexity of the data on the one hand, and the urgency to take action on the other hand. Our results suggest that a deep understanding among the public concerning climate change issues might not be a realistic goal: “we will never be able to convey this complexity to everybody” (CC-2). Rather, it is important to establish a trust in science (e.g. [70]), and to effectively convey the most important messages to the public. In this context, van der Linden et al. [71] found that the scientific consensus about climate change topics “is most effectively communicated as a short, simple message that is easy to comprehend and remember”. A further aspect that makes climate change visualizations stand out is the emotional aspect, which can also be triggered by design choices. The interviews with BC participants shed light on how some of them liked a more dramatic design, whereas others were very reluctant to such perceived “horror scenarios” and felt manipulated. The feeling of responsibility for the current situation, fear about how the future might look like, and the perceived need/social pressure to change one’s personal behavior make climate change communication all the more complex. Especially, acknowledging the need for a personal change in behavior is inconvenient for many people. Hence, not only a lack of interest in and or understanding of climate change, but also cognitive phenomena, like the status quo bias (e.g. [72], [73]), could restrain us from giving “climate action the high priority it is due” [2, p. 3]. Similarly to previous work (e.g. [74]), our results show that messages are most effectively framed in a positive solution-oriented way, but also in a way that evokes emotions, e.g. by showing concrete consequences (e.g. [75]).

5.3 Limitations and Future Work

As with every study our findings have to be understood within the limits of the study design. While the sample size, at which data saturation is normally reached, was exceeded [48], [49], the interviews are still limited in number and in respect to the included fields of expertise. Furthermore, our sample shows a focus on European and on [country name removed for review] participants, with some of them making their arguments for local circumstances. With a focus on expert opinions and the smaller BC sample, we can only make cautious inferences on how one or the other design choice would work for the general public. We identified important themes for public climate change communication, but further studies are necessary to test concrete assumptions. While the example visualizations were very helpful in encouraging a discussion, and in part also led to experts sharing their general recommendations, both used visualization pairs depicted graphs with a time axis and temperature trends. Using different visualizations or visualization types might have resulted in other aspects coming to light. Finally, our questions were aimed at opinions about broader themes, hence, results might
(in part) not be specific to climate change data visualizations, but apply to data visualization and science communication in general.

Future research could address some remaining open questions regarding visual climate change communication to the public. A more large-scale analysis could shed light on how data visualizations about climate change are created and used in news media sources. Their understandability could be investigated with a larger sample of lay users, which is representative for the general public. It would also be interesting to test different design options (e.g., including/excluding uncertainty or other details) and how this affects readers' understanding or how different visualization types/design choices perform in catching the readers' interest. Those approaches could help to inform how climate change can be communicated to lay audiences and how journalists can translate scientific contents into effective visualizations for the public.

6 Conclusion

Communicating climate change not only to decision makers but also to the public is one of the big challenges of our time in order to raise awareness and understanding and finally to facilitate action. With climate change communication experiencing a shift toward visualization, visuals are used by a variety of stakeholders to achieve a number of different goals. However, visualizing climate change data in a way that makes it accessible for different audiences while still maintaining scientific accuracy is difficult. On the basis of expert interviews, we derived implications for creating more effective climate change data visualizations, particularly in news media sources geared toward lay audiences.

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