From shock to shift: Data visualization for constructive climate journalism

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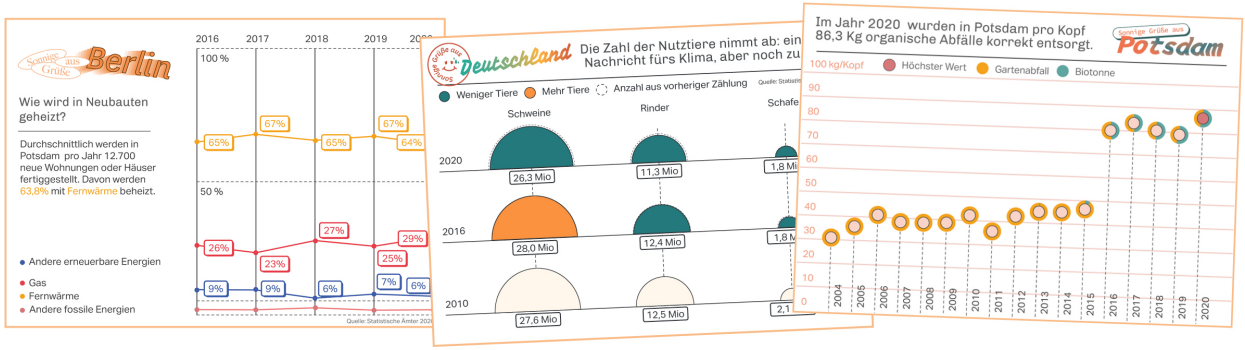

Fig. 1: Klimakarten are postcards that visualize the progress in climate protection in five critical sectors, from national to local levels, and across digital and analog channels. The visual design aims to encourage affective engagement with climate protection.

Abstract—We present a multi-dimensional, multi-level, and multi-channel approach to data visualization for the purpose of constructive climate journalism. Data visualization has assumed a central role in environmental journalism and is often used in data stories to convey the dramatic consequences of climate change and other ecological crises. However, the emphasis on the catastrophic impacts of climate change tends to induce feelings of fear, anxiety, and apathy in readers. Climate mitigation, adaptation, and protection—all highly urgent in the face of the climate crisis—are at risk of being overlooked. These topics are more difficult to communicate as they are hard to convey on varying levels of locality, involve multiple interconnected sectors, and need to be mediated across various channels from the printed newspaper to social media platforms. So far, there has been little research on data visualization to enhance affective engagement with data about climate protection as part of solution-oriented reporting of climate change. With this research we characterize the unique challenges of constructive climate journalism for data visualization and share findings from a research and design study in collaboration with a national newspaper in Germany. Using the affordances and aesthetics of travel postcards, we present Klimakarten, a data journalism project on the progress of climate protection at multiple spatial scales (from national to local), across five key sectors (agriculture, buildings, energy, mobility, and waste), and for print and online use. The findings from quantitative and qualitative analysis of reader feedback confirm our overall approach and suggest implications for future work.

Index Terms—Constructive Climate Journalism, Frameworks, Storytelling, Journalism

1 Introduction

Data visualization is widely used to explore data about the climate crisis and communicate its implications [1]. Climate journalism is a genre of reporting focused on making the consequences of the climate crisis visible and understandable to lay audiences [2]. In recent years, data visualization has assumed a central role in climate journalism. Newsrooms have established dedicated teams to develop extensive journalistic projects focused on environmental issues [3] and data visualizations are often used to convey the causes and consequences of climate disasters. The usage of visualization to present the negative results of climate change helps make abstract data tangible for readers. Nonetheless, the emphasis on the negative implications of climate change can also induce feelings of fear, anxiety, and lack of agency in readers [2,4–6]. Yet, climate change cannot be reduced to its ecological and social consequences—connected topics such as climate protection are highly relevant and need to be communicated as they have the potential to orient readers toward a political and cultural shift. Climate protection refers to the institutionalized effort of applying short and long-term strategies to reduce greenhouse emissions generated through human activity [7]. Data visualizations can play a crucial role to convey solution-oriented approaches and its intrinsic complexity. Previous research already pointed to data personalization [8], localization [4], and diversification across channels [9] as critical points for climate change communication. However, little research has focused on the interplay of these strategies for data visualization and how they can be mobilized to craft data stories related to climate change.

Following prior research from the fields of media and communication, digital journalism studies, and information visualization, we understand climate change communication as a multi-dimensional, multi-level, and multi-channel enterprise. We propose an approach to visualization design for climate journalism that translates these domain challenges into concrete design goals for data visualizations. The aim is to foster readers' affective engagement—namely their emotional involvement [10]—with climate protection and promote a shift from

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negative feelings of shock and hopelessness to positive and actionable attitudes. To explore the viability of our approach and learn about readers' emotional response we carry out a design study [11, 12] as part of a journalistic-academic collaboration on visualizing climate protection. Using the affordances and aesthetics of travel postcards, we present *Klimakarten* (German for "climate cards"): Climate visualizations that represent progress of climate protection at multiple spatial scales (from national to local), across key sectors (agriculture, buildings, energy, mobility, and waste), and for both print and online use.

In short, this paper contributes an approach to data visualization for constructive climate journalism—the positive and educational reporting of climate related news [13]—by creating sets of climate protection visualizations that span sectors, levels, and channels. We validate the approach with quantitative and qualitative analysis of readers' feedback and share how the visualizations influence readers' affective engagement. Personal relevance and localization of the visualizations are particularly important to make readers feel more engaged.

2 Related Work

There is considerable work on data visualization for climate journalism and data stories, but very little research on how to enhance readers' affective engagement with constructive coverage of climate change. Our work is a step towards this goal.

2.1 Data visualization in journalism

The importance of data visualization for science communication is recognized and applied across many domains [14]. Journalism scholars consider data visualization a key technique for climate reporting. Data visualization is used to cover climate change as it supports outlets in producing coverage that stands out and can act as a bridge between activists, reporters, and scientists [15]. A particular quality that is ascribed to data visualization is its capacity to engage audiences with complex topics like climate change, however, some also question its impact as too much linked with traditional reporting [3]. Apart from the social and communicative impact of visualization, there has also been considerable work on visualizations for data journalism. For instance, some authors have proposed visualization tools and visual techniques for a wide variety of journalistic data stories. For example, *netflower* is a visual exploration tool that supports journalists in the analysis of quantitative data flows [16]. Similarly, the tool *newsleak* [17] was designed to support investigative journalists to make sense of leak data.

Additional research has concentrated on the development of design frameworks for journalistic visualization. One study [18] demonstrated how visualizations of social media data can help journalists identify potential news leads and create data stories. Another investigation [19] established a task-sensitive process to assist journalists in selecting the most suitable visual representation for their data. Moreover, multiple studies have focused on specific applications, such as health data [20], data videos [21–23], and sonification [24] for data journalism.

In the context of climate journalism and visualization, one study [25] examined the role of visual storytelling and data visualization in communicating environmental justice data. This research highlighted the significance of multidisciplinary and cross-field processes in fostering novel inquiries among students and practitioners in the field. Another group of researchers [26] created a set of guidelines to aid domain experts in designing comprehensible, clear, and scientifically accurate visualizations, thus facilitating effective communication among stakeholders and experts. However, there remains a need for design principles and practical approaches to effectively convey climate change-related topics through data stories to general audiences.

2.2 Barriers to effectively communicate climate change

Over the years, scholars have been debating how to overcome the barriers that prevent readers from informing themselves about climate change. Besides facilitating the knowledge exchange between scientists and policy-makers [27], there is the need for citizens to peruse scientific information in a more accessible manner to provide more context when deliberating environmental policies [28]. More recently, the interplay between citizens' attitudes towards climate change and their social, cultural, and economic context has also been taken into consideration [4]. The role of participatory sense-making, involving scientists closely communicating with community members, has been extensively analyzed and it has been found to elicit interest and active involvement in addressing climate-change-related problems [29, 30]. Several researchers have pointed out key barriers to the communication of climate change, including but not limited to data variety and analytical complexity [31], lack of local and personally relevant data [4], as well as inter-generational gap and feelings of frustration toward the inaction of other citizens [5]. Despite these efforts and the open challenges, there is still limited understanding about designing engaging visualizations to communicate climate change and its associated topics.

2.3 Studying engagement towards visualizations

Previous literature has studied the effects of data visualization on engaging diverse users and audiences, in both online and offline settings. A recent study [32] has found that visualizations have a higher likelihood of influencing readers' attitudes compared to other visual artifacts, such as illustrations. Researchers have also examined other aspects of visualization, including the roles of aesthetics [33], storytelling [34, 35], prior knowledge [36], and personal background [37] in user engagement. The aesthetic style of a visualization has proven to impact the self-reported usability, enjoyability, and usefulness of a visualization and enhance users' interest, by fostering more reflective and interpretative sense-making [33].

However, storytelling has not been shown to significantly increase user engagement with visualizations. One study [34] investigated the time and attention of users and found that they do not engage longer with storytelling-enhanced visualizations. More generally, the impact of storytelling on readers' attitudes has been challenging to quantify [35]. Another paper [36] found that readers of data journalism stories were not influenced by prior knowledge, but that visualizations were more effective in comparison with text in changing readers' attitudes on contentious topics.

Various methodologies and frameworks have been devised to evaluate engagement with data visualizations. One such example is VisEngage, a self-assessment questionnaire [38] to gauge user engagement with visualizations based on eleven characteristics, ranging from novelty or interest to captivation. The same authors contributed to the scholarship on users' engagement by going beyond the traditional quantitative metrics and introducing the concept of affective engagement to study users' emotional patterns when exposed to visualizations [10]. Another study investigated engagement from a qualitative point of view [39], considering how newspaper readers commented on data journalism pieces. The authors proposed an analytical framework to categorize comments on visualizations to better understand readers' engagement with representation and topic. Further research on attitudes and perception of visualizations has shown the substantial impact of personal background such as level of education, political affiliation, and personal experiences on attention and sensemaking [37].

Prior work on data visualization for journalism and storytelling explored the impact of visualization on user engagement, but there has been limited work on communication barriers related to climate change. Moreover, the development of design principles and practical approaches for climate change-related data stories to general audiences remains underexplored. We aim to address these gaps by focusing on data visualization for constructive climate communication and studying readers' affective engagement with climate protection visualizations.

3 Visualization for Constructive Climate Journalism

Engagement can be defined as an experiential attribute of interfaces, including visualizations, with dependencies on users' decision-making [40]. Engagement concerns the emotional, cognitive, and behavioral connection that exists between a user and a resource in or over time [41]. The effective communication of climate change as "the multi-factorial behavior of a complex system" requires clear and actionable design strategies [42]. Given its complexity, which often triggers either anxiety or indifference in readers, we explore the emotional aspects of engagement in the context of constructive climate journalism.

We follow Hung and Parsons' definition of affective engagement as the "user's emotional involvement or investment while interacting with a visualization" [10]. Affective engagement extends beyond usability and considers users' subjective experience with visualizations. This concept is crucial for climate data visualization, as it allows to move from the notion of users' engagement with an interface to readers' emotional and intellectual investment in a topic. Focusing on affective engagement is key to counterbalance negative and fear-inducing coverage of climate change, and promote the authoring of positive and constructive data stories that shift from focusing exclusively on climate change to include topics such as climate protection and mitigation.

3.1 Domain challenges

Drawing from research on climate change communication, we identify three challenges for visualizations to be used in constructive climate journalism.

Multi-dimensionality Climate change is a multi-dimensional phenomenon. Climate-related data are heterogeneous (spatial, temporal, multi-variate, etc.) and require a variety of different visualization techniques to be appropriately represented [43]. Previous research has addressed the problem by defining a series of design principles for multi-dimensional climate data visualization, considering level-of-detail, granularity, and comparability as key challenges that need to be addressed in the visualization process [26]. Beyond the multi-dimensionality of data, practitioners also have to deal with the breadth of the topic itself. The scope of climate crisis implications goes beyond environmental and natural science and affects nearly all aspects of society, economy, politics, and culture. Navigating extensive information and finding relevant climate data is not straightforward, even for domain experts [31]. This analytical bottleneck also impedes the sense-making carried out by lay audiences (i.e., newspaper readers) in trying to make sense of climate-related problems. Conveying comprehensive information using climate-related data is a difficult task for visualization practitioners, especially considering the limited space allocated to visualizations in articles and the readers' limited attention span and motivation.

Multi-level Climate change unfolds on multiple levels, from global to local, from structural to individual. The absence of locally-relevant and personal information has been identified as a barrier to engage readers [4]. When presented with large-scale visualizations, readers struggle in understanding the impact of climate change on their daily lives. Feelings of helplessness and the fear induced by negative messages [2] undermine the influence of climate reporting on newspaper readers. Data visualization can play an important role in emphasizing the personal and emotional components of climate change. Early research on data visualization for climate data has documented the development of participatory data practices that aimed at localizing, spatializing, and visualizing climate change implications on selected neighborhoods [44]. As such, there is a need to study the persuasive potential of visualizations to engage emotions through visual imagery. Going beyond its analytical role, data visualization has already been proved to elicit strong emotional reactions among users and readers [8]. Localization and personal relevance are essential for communicating climate change. Such sensemaking should not be limited to education, but also support readers' activation and motivation to participate on social, personal, and political levels [3]. To date, it can be challenging to localize climate data in a scalable and intelligible manner.

Multi-channel Climate change is a planetary challenge that cuts across generational [45] and cultural [46] boundaries. Considering differences in media reach according to readers' age, trust, and interests [47], reaching several groups of readers with different news consumption habits is a challenge for journalists. Distributing climate visualizations in multiple channels could help reach beyond the group of traditional newspaper readers. Different channels are often complementary and can support each other in structuring communication [9]. Nonetheless, multi-channel strategies should take into account the specific characteristics and conventions of the respective communication settings and meaningfully translate the visualization to fit within its context of media use [48]. To this day, the knowledge of how multi-channel visualization projects potentially impact users' engagement is limited. Especially in combination with the multi-dimensional and multi-level character of climate change, the viability of multi-channel visualizations is yet to be thoroughly investigated.

3.2 Design goals

Identifying the domain characteristics that are specific to climate change communication provides a segue into the formulation of design goals [DG] for visualizations of climate-related issues. In the following, we pose five ambitions for the design of data visualizations in the service of constructive climate journalism.

Encourage hopefulness [DG-hopeful] Understanding the causes and consequences of climate change can be a daunting task considering the dire projections of some scenarios. We intend to use visualization to encourage hopefulness and mitigate climate anxiety in readers. To reach this goal, we explore different visual aesthetics, metaphors, and formats. From a content perspective, we intend to address topics constructively, by proposing solutions, positive future scenarios, and contextualized data interpretations.

Offer low-threshold access [DG-access] The complexity of climate-related metrics and indicators can pose a barrier to lay-audiences. Visualizations should support readers in overcoming this analytical bottleneck and comprehending the implications and extent of climate change. We set this goal with the idea of prioritizing clarity during our design process. Information should be delivered in digestible chunks and accompanied by clear explanations. Visualizations should entice curiosity and suggest readers to keep exploring and analyzing.

Make visualizations personally relevant [DG-personal] The absence of personally relevant information is a known obstacle for readers struggling to engage with climate change data. One way to increase personal relevance can be the inclusion of local or regional information and considering societal and cultural influences as an important part of data selection. Visualization projects for constructive climate journalism should prioritize local datasets besides national ones.

Support sharing of insights [DG-share] Visualizations of climate change should be easily shareable among readers to promote participation in discussions about upcoming societal and economic transformations. Because datasets do not speak for themselves, readers should be able to exchange thoughts and reactions in the context of the visualizations to facilitate affective engagement with the topic.

Devise coherent forms across platforms [DG-format] Journalistic projects on climate change should appeal to readers with widely varying news consumption habits. Given the numerous platforms and communication channels currently used by journalists, it is crucial to target audiences in different contexts and through different formats. The visualizations should be modified to fit these settings rather than merely being duplicated and disseminated across channels.

3.3 Research approach

The above design goals respond to the domain challenges of constructive climate journalism in the language of visualization and interface design. Below we present a case study set out to implement these goals and study how they play out individually and jointly during the design process. We devised the case study to understand the translation of general challenges and goals into concrete design decisions. To do so, we set up the project to be participatory and include iterative co-design sessions, engaging our collaborators in workshops and running feedback sessions with relevant stakeholders and experts during all ideation and prototyping phases [11]. We sought cooperation with a newsroom, to better relate to journalistic workflows and reach more diverse audiences. In our analysis, we do not compare different demographic groups, visualization techniques, or communication channels. Instead, we use the concept of affective engagement to study the viability of our approach and learn more about its potential from reader responses.

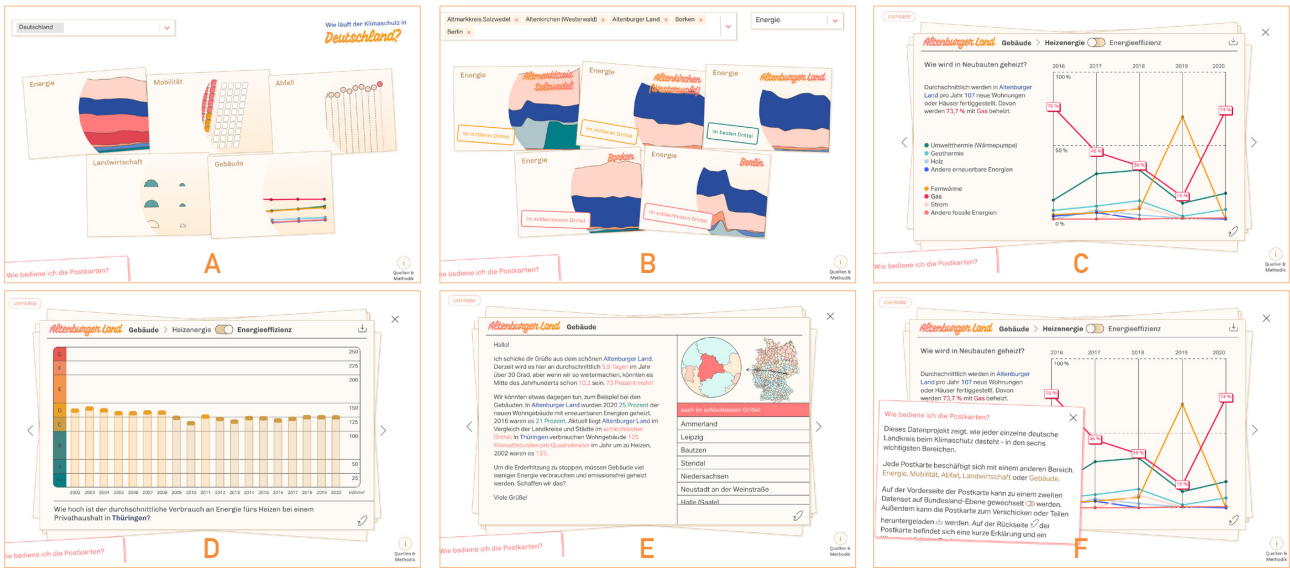

Fig. 2: Different states of the online visualizations: Initial state with national postcards of each sector (a), comparison of multiple districts for one sector (b), front side of an opened postcard (c), front side toggled to the second indicator (d), back side (e), and expandable tutorial (f).

4 KLIMAKARTEN: POSTCARDS FOR CLIMATE PROTECTION

The Klimakarten project took place between May 2022 and January 2023 in cooperation with *taz, die tageszeitung*, a cooperatively owned major daily newspaper in Germany. As of 2019, taz readership is composed of 41% women and 59% men [49] and most of its readers are above the age of 50 (82%), among these 52% are 60+. The second largest group of readers is between 40 and 49, which account for 12% of the readership. Lastly, readers spanning between 20 and 39 make up only 6%. Politically, the majority of taz readers are left aligned, with a preference for the German green party. Our team consisted of two expert reporters, one editor, two designers, one computer scientist —belonging to the taz newsroom—, developers with academic experience, and two information visualization scholars — coming from the academic side of our cooperation. The newsroom team took care of providing data sources, making editorial decisions, offering feedback on the visualizations, and supporting their integration on the taz platforms. The academic team worked on creating the technical infrastructure to co-design data and visualizations, as well as practically developing the outcomes across offline and online channels. The overarching goal was to address the challenges of constructive climate journalism while pursuing the aforementioned design goals. We explored various concepts for the project, including the idea of producing local coverage on climate protection strategies in Germany. Climate protection requires profound political and social changes which have to be approached through citizens' consensus and participation. Through constructive climate journalism, journalists can bring forward potential solutions and support readers in understanding complex scientific data. To this extent, the design process for climate protection data visualizations needs to be approached carefully, to avoid feelings of helplessness in readers. For all these reasons, the project focused on communicating the progress of climate protection with the main objective of supporting readers in answering the following basic question: *How is climate protection going in Germany?* The result is a set of digital and print postcards for five sectors at national, regional, and local levels (see Fig. 3).

4.1 Data selection

Successful climate protection strategies affect various sectors and domains of society, both at national and local levels. Several aspects have to be taken into consideration to discuss and communicate climate protection. Since we aimed to achieve low-threshold access to the topic [DG-access], we developed indicators for climate protection at the national, state, and district level, following the guidelines of the German Institute for Economic Research (DIW)[1]. Indicators are useful to break down climate protection according to reachable and tangible goals. Our indicators covered the five main sectors mobility, buildings, energy, agriculture, and waste. In accordance with the DIW guidelines, we looked for data that are recorded routinely, publicly available, and on a temporal level. An important constraint at this point was to avoid displaying these indicators only at a national level. Following DG-personal, we intended to create personally relevant visualizations that could adapt to the reader's interests. Therefore, we sliced them according to two levels of granularity: the first layer of data had to offer a general overview of Germany and its states, the second needed to go down at a local level, comprising 400 districts. All sectors aside from waste were based on two indicators, one on the district level, the other on the state level. For the mobility sector, we considered car density (the number of cars per 100 inhabitants) and modal split (the percentage of commuters using a particular mean of transportation). The buildings sector included the type of heating energy installed in new buildings and the level of energy efficiency of households. The energy sector comprised the energy consumption of industry and the total energy demand. For the agriculture sector, we collected the absolute number of livestock and their density per square meter. Waste was exemplified by the local production of biowaste in tonnes. All data aside from modal split are publicly available data from Destatis[2], the Federal Statistical Office of Germany. Modal split data were part of the national survey about mobility in Germany[3].

4.2 Design concept

Given the overall complexity and to avoid climate anxiety or information overload [DG-hopeful], we started to work on a coherent style and visual metaphor for the visualizations. Rather than embedding charts in a dashboard or within a journalistic story, we decided to create individual data-driven postcards for each sector with one visualization on the front side and a concise explanation on the back. Postcards are photographic or illustrated cards typically sent via mail from holiday locations [50]. As the Dear Data project has demonstrated [51], the format of postcards lends itself very well to data visualizations. We chose to work with postcards because the object itself presents a series of useful affordances for developing our project:

[1] https://tinyurl.com/mr2nxxup
[2] https://www.destatis.de
[3] https://bmdv.bund.de/goto?id=229732

- Postcards are familiar and collectible objects, they present recurring graphical elements and patterns. It is common for postcards to look similar or alike. This opened up the possibility to design a virtually infinite number of artifacts that sliced the data according to districts [DG-personal]. They also allow for custom designs and adaptations across channels [DG-format].
- Postcards can have a visual and conceptual lightness: they are sent from holiday locations, usually from friends and family. This aspect allowed us to work with the vintage aesthetic of postcards and give visualizations a distinct mood [DG-hopeful].
- Postcards are self-contained, they include simple and personal messages and do not require additional context. This feature forced us to keep the information on each postcard concise; each visualization presented a title, short description, and geographic provenance [DG-access]. The back included a short description and left space for adding a personal message [DG-hopeful, DG-access, DG-personal, DG-share].
- Postcards are meant to be sent to someone. This characteristic gave us the opportunity to encourage readers to actively participate by including calls to action on the back side of the postcard [DG-share].

4.3 Postcards

For every sector we developed two visualizations, one for each indicator. We created one postcard per climate protection sector: the main visualization of the relevant indicator on the front and contextual information on the backside, such as explanatory text and geographic location. The design and usability of the postcards change depending on the channel [DG-format]. Online and offline versions of postcards present different layouts and page compositions, however, they contain the same information and visualizations. Some details of the visualizations or descriptions are conditionally included or omitted. Both offline and online readers were presented first with postcards at the national level. Offline readers had limited options to compare and localize postcards and had to change to the online version in order to be able to see more districts and combine sectors.

Online On the newspaper website , postcards are presented as part of an interactive application (see Fig. 2 and 3 (b)). The application is available both for mobile and desktop devices [DG-format]. Initially, readers are presented with a preview of five postcards on a white background. The postcards are positioned at the center of the screen and in this first state, their disposition recalls the image of a stack of postcards displayed on a table [DG-hopeful]. This initial stack of postcards shows all five sectors for Germany in miniature versions to act as previews (see Fig. 2 (a)). On each postcard preview, the name and ranking of the sector are included, as well as an excerpt of the visualization. The ranking was calculated by dividing each district into either upper, medium, or lower third for each sector compared to other districts. This gives the reader an easy entry point to compare and comprehend the data [DG-access]. At the right top corner of the dashboard, there is a short title reading "How is it going with climate protection in Germany?". By changing location, this title updates to reflect the name of the selected location [DG-personal]. On the top left corner of the dashboard, there is a search bar preset to Germany. Readers can use it to see the stack of postcards for any other location [DG-access, DG-personal]. When readers select only one location they enter localization mode: the set of postcards is substituted and readers can look at all sectors from the selected location together [DG-personal]. If readers select more than one location (up to five) comparison mode is activated: an additional search bar substitutes the default title at the top right corner and only one sector is shown [DG-access, DG-personal] (Fig. 2 (b)). By using the additional search bar, readers can navigate through sectors. Readers can tap or click on the postcards' previews to 'pick up' an individual postcard from the stack. Upon selection, the postcard animates and moves closer to the reader enabling them to look in detail at the visualization displayed on the front side [DG-hopeful, DG-access] (Fig. 2 (c)). Together with the visualization, the front side includes the name of the location [DG-personal], an explanatory caption [DG-access], a switch to change indicator [DG-access] (Fig. 2 (d)), a download button to create a social-media-friendly version [DG-share], and a button to flip the postcard [DG-hopeful, DG-access]. On the back side, there is a text, which is automatically customized depending on the district and explains the indicators for each sector and their broader impact on climate change. Two additional widgets are also displayed on the back: a list of locations with similar scores for the selected sector [DG-access], and an interactive map of Germany that can be used to navigate across locations [DG-format] (Fig. 2 (e)). Outside of the postcard frames, on the left and right sides, two arrows can be used to navigate between visualizations. On the bottom-left of the screen, a short expandable tutorial on how to use the application is included (Fig. 2 (f)). Visualizations have also been extrapolated from the applications and posted across the newspaper's social media accounts. Figure 3 (c) shows how the graphics have been adapted for Instagram, a platform to share photographic and video content.

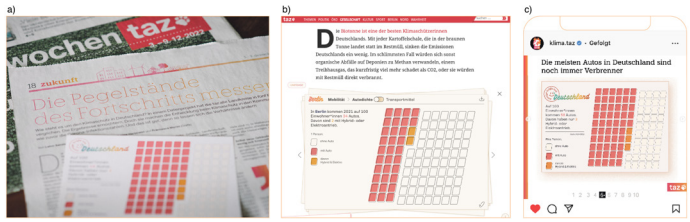

Fig. 3: Postcards were published online and offline. Offline, they have been included in the newspaper both as graphics and as a supplement (a). Online, postcards were published within relevant articles on the newspaper website (b) and across all their social media channels, including Instagram (c).

Offline Printed postcards have been included in the weekend issue of the newspaper both as a supplement and graphics (see Fig. 3 (a)). The postcards included in the newspaper portrayed the sectors for Germany and were printed on a specially folded leaflet [DG-format]. The leaflet takes inspiration from old decks of postcards: the sides can be unfolded and ripped off to separate the cards [DG-hopeful, DG-share]. For selected cities, we printed and hand-delivered postcards with local indicators [DG-personal] on standard postcard paper in A6 format (14.8 x 10.5 cm). As shown in Fig. 1, printed postcards present more detailed data visualizations with annotations and larger labels [DG-access]. On the top left corner of the postcard, the geographic location is specified. The name of each city presents its unique style and decorative elements [DG-hopeful] (Fig. 1). On the back side, a short explanatory text is provided with specific information about the indicator and location [DG-access]. Below the text, we included a QR code to the survey and a link to the online version of the postcards to motivate readers to keep exploring other locations [DG-format]. A map and a list of similar locations are omitted in print to leave space for personal messages [DG-share].

4.4 Visualizations design

Each dataset has been translated into a unique visual representation, resulting in a diverse set of motives, charts, and colors. Visual representations depend on the data — their structure and topic. By creating different representations, we supported readers' understanding of individual indicators [DG-access]. By working with metaphors tying topics with data [DG-hopeful], we aimed at enticing their curiosity:

- Mobility — this postcard includes two indicators: the number of cars owned per capita and modal split. The former is represented as a waffle chart (Appendix A, Figure A) where each colored square represents one car and the color marks the type of engine. The chart recalls the shape of a parking lot, where each square is a space taken up by a car. The latter is depicted as a set of folded bars showing the number of kilometers traveled with one type of transport. The visualization reminds of a curvy pathway (Appendix A, Figure B).

- Buildings — the indicators for this sector are the type of heating installed in new buildings and households' energy efficiency. The first visualization is as a multi-line chart, each line corresponding to an energy carrier (Appendix A, Figure C). Energy efficiency is visualized with the same colors and visual style of the European Energy Certificate System (EECS) labels, commonly shown on house prospects. Each bar corresponds to one year and shows the average kWh/m^3 for buildings, the color represents its efficiency (Appendix A, Figure D).
- Energy — this postcard accounts for two datasets: one on the overall electricity consumption, one focusing on industrial electricity consumption. We use the same visual representation for both indicators: a stream-graph, where each source of electricity is marked by a distinct color (Appendix A, Figures E and F).
- Agriculture — the indicators for agriculture are the number of livestock and their density per square meter. We represent the first as proportionals area chart, loosely recalling the shape of pig shelters. The color of the semi-circle encodes the change in livestock, the size its current quantity on the baseline year (Appendix A, Figure G). Livestock density is shown using a stacked bar chart, comparing years and livestock density (Appendix A, Figure H).
- Waste — this postcard includes only the yearly organic waste production. We combine a lollipop chart, to show the increase and decrease in overall waste production (Appendix A, Figure I). Around each dot, we wrap a donut-chart to break down the share of household-produced organic waste and pruning waste.

4.5 Publication and distribution channels

Postcards were subsequently published across the newspaper platforms. Online postcards were embedded using iframe elements in several articles published free of a paywall in the digital edition. Journalists were able to customize the embed based on the story by using the iframe's URL to change a set of given parameters [DG-personal]. This allowed them to show local visualizations, hide or show accessory elements of the UI, and remove some of the sectors based on the story [DG-access]. Simplified versions of the postcards were also published on the official Instagram profiles of the newspaper with links to online articles [DG-share]. To increase the reach beyond usual newspaper readers, postcards were included both on the main newspaper account and on the climate-related account @klimataz. As mentioned above, for the printed edition of the newspaper, four postcards on the national level were printed and distributed with the newspaper for subscribers. Additionally, in order to reach casual readers, postcards were included in one of the featured stories as graphics, and local postcards for Oldenburg, Potsdam, Brandenburg, and Berlin were hand-delivered at events, conferences, bars, and shops. The cities were selected because of specific events organized by the newspaper, and because they provide contrasting insights into climate protection in urban and rural areas.

5 Studying Affective Engagement

We consider affective engagement to be a crucial marker for understanding the viability of our approach. To study how readers engaged with the visualizations, we followed a two-fold methodology. First, we focused on the quantitative aspects, namely the readers' attention, interest, and ability to clearly understand the visualizations. Building on top of these quantitative measures, we explored the qualitative aspects of engagement: Readers' activation, motivation, and emotional response. To conduct both sides of the analysis, we created a survey with a mix of quantitative and qualitative questions as self-reported gauges for affective engagement. The survey was identical for printed and digital postcards, with some minor rephrasing to accommodate the change of format and readers' channel of provenance namely their preferred way to access the postcards. Participants in the survey could sign up to win a gadget from the newspaper with a value of 35 euros. Online readers could access the survey through a link displayed at the top of the visualization. The link did not hinder readers to use the visualizations but was briefly animated to attract attention in the first couple of seconds. Offline readers could access the survey through a QR code printed both on the newspaper page and on single postcards.

5.1 Survey Questions

In the first part of the survey, we included preliminary questions useful to categorize groups of readers. We asked from which channels readers were looking at visualizations (online, offline, or both), and which postcards they looked at. Following with this initial round of questions, we moved on to the analytical part of the survey. Quantitative questions were in part based on Hung and Parsons' criteria for measuring engagement with data visualizations [38]. Readers were asked to answer a series of statements that evaluate aspects connected with the format and content of the visualizations. Answers were measured through a Likert scale going from 1 (strong disagreement) to 7 (strong agreement). We investigated the following aspects:

- Interest: *"The content and message of the data visualization were interesting to me."*
- Perceived novelty: *"I learned something new."*
- Visualizations clarity: *"The data visualizations were understandable."*
- Content clarity: *"The descriptions were understandable."*
- Perceived importance of local information: *"The local information and format were helpful."*
- Autotelism: *"I would look at the postcards somewhere else."*

Qualitative questions were formulated to expand on the notion of readers' affective engagement. We asked readers to report on their thoughts, ideas, and intentions when looking at the visualizations. These variables are difficult to measure as they do not rely entirely on quantifiable variables but on readers' emotional and attitudinal states. Hence, we added four long-form questions to the survey. Questions are formulated to obtain insights into their emotional reactions, and ability to form a critical opinion as well as remember details. We kept questions optional and open for interpretation:

- *What can be seen on the postcard?*
- *With whom would you share the postcard?*
- *What message would you write on the postcard? And why?*
- *What aspects of the visualizations can you remember?*

5.2 Analysis

In total, 216 readers took part in the survey. To make sense of the responses, we used a mixed-method approach combining quantitative and qualitative analysis.

5.2.1 Categorization of respondents

We categorized each reader according to their channel of provenance: online through social media and the newspaper website, offline through printed postcards or newspaper, and mixed through a combination of offline and online channels. 105 readers (48.6%) saw the visualization only offline, 78 (36.1%) exclusively online, and 33 (15.3%) reported to have seen them both offline and online. We differentiated between readers that used the comparison and localization modes and the ones who did not. Readers that reported having seen more than one location or that referenced data of specific districts in their answers were assigned to the first group and the remaining readers to the second. The majority of users (65.3%) did not use localization and comparison features. Readers who compared multiple sections and locations (34.7%) came from online (21.8%) or mixed (12.5%) channels. The channel of provenance appears to be connected with the use of localization and comparison features of the visualizations. In the online version, the readers could explore localization mode by searching for a district, and comparing different locations, which was practically only possible with physical cards by juxtaposing them.

5.2.2 Quantitative analysis

The aim of the quantitative analysis is to assess readers' engagement with the postcards and characterize different groups of users. Characterization is instrumental for two reasons. On the one hand to investigate whether localization features or channel of provenance influenced positive and negative engagement from readers. On the other hand to

identify groups of readers with similar ratings and patterns of reactions and understand if there are significant differences in how readers from these groups perceived the project. Hence, the quantitative analysis addressed three questions:

[Q1] *What are distinct groups of readers with similar patterns of engagement?*

[Q2] *Does engagement differ between people based on their channel of provenance (online, offline, mixed)?*

[Q3] *Does engagement differ between people based on their ability to localize and compare different locations?*

To address Q1, we used a clustering approach. This enabled us to consider all six Likert scale answers in the survey equally. For clustering, k-Means++ has been performed using the unprocessed Likert-scale answers [52]. K-Means is a standard clustering algorithm to partition observations in a given number of clusters. The appropriate number of clusters for our sample lied between four and five and has been determined using gap statistics [53]. Silhouette score has been used to determine the quality of our clusters [54]. As suggested by Luxburg et al. [55], we also considered soft factors in determining the quality of clusters by manually checking scores and qualitative answers. We defined five clusters of users with similar patterns of response: readers with high scores (6—7) across all quantitative questions (cluster 1, n=61, 29.2%), readers with low scores (below 4) across all quantitative questions (cluster 2, n=25, 12%), readers with balanced scores (cluster 3, n=63, 30.1%), readers that scored low only on the question of novelty (cluster 4, n=32, 15.3%), and readers with low scores on the question about format (cluster 5, n=28, 15.4%). To determine statistical significant differences for the channel of provenance and localization/comparison features the non-parametric Kruskal-Wallis [Q2] and Wilcoxon-Rank-Sum [Q3] tests have been used. For significant results—following Cohen [56]—we assessed the effect size.

5.2.3 Qualitative analysis

Whereas quantitative analysis has been used to determine readers' level of engagement, we used qualitative methods to investigate affective engagement and its subtle differences in readers' tone, activation, and behavior. The qualitative analysis answered the following questions:

[Q4] How does the design concept influence readers' affective engagement towards the topic of climate protection?

[Q5] How does a multi-channel strategy affect readers' affective engagement with the topic?

[Q6] How do localization and comparison influence readers' affective engagement?

Responses to surveys were categorized using a mix of existing analytical frameworks and coders' individual sense-making. Three coders have worked on the categorization, iterating over comments and refining the final version of the codebook. First—following Hullman et al. [39] framework for categorizing commentary to journalistic data visualizations—we divided statements into context-oriented or content-oriented, and critical or non-critical. Context-oriented comments refer to the reader's contextualization of the visualization. Content-oriented comments reference explicitly the visualization or the data represented. Then, comments were coded according to emerging categories and patterns. As a result, statements have been coded according to six categories: topic, hypothetical recipient of the postcards, attitude towards the format, memorable elements, content, and context. For each of these categories, two or more subcategories have been included.

5.3 Results

Below we describe our key observations from both the quantitative and qualitative analysis. Quotes from readers are identified by the letter R followed by a unique number for each reader, the channel of provenance (online, offline, mixed) and the assigned cluster (C1 – C5).

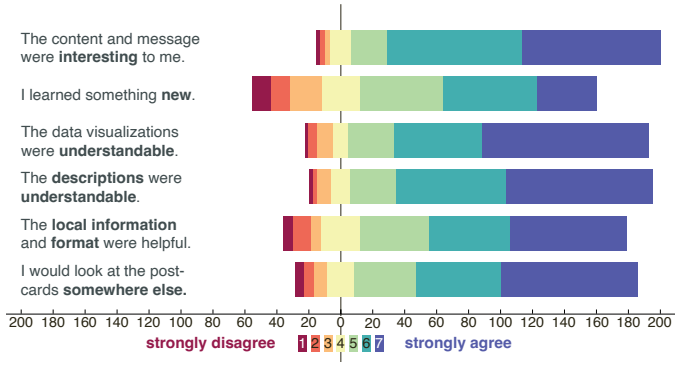

Fig. 4: The absolute number of ratings for quantitative questions from 1 (strongly disagree) to 7 (strongly agree).

5.3.1 Design concept

In assessing if the design concept has any influence on readers [Q4], we found that the concept of postcards to design visualizations was predominantly perceived as helpful. As visible in Fig. 4, 77.5% of readers (n=162) rated the statement "I found the postcard format and local information helpful" with 5 points or more. Concerning the design concept, there was no significant difference neither across channels of provenance [Q2] nor among people that used localization or comparison features [Q3]. Readers that appreciated the project in general belong to clusters 1, 3 and 4. They presented a high level of positive emotions. The possibility to look at the development across sectors led to feelings of hopefulness. Other positive feelings included remembering a specific positive local example, a positive trend in a sector, and feelings of hope and motivation:

> "*Most of the visualizations confirm my general estimations, but I am positively surprised that there is a slight decrease in industrial breeding of animals. A small ray of hope. In general, I find the project very successful [...]. I also like the twist to address the recipient. Makes you smile slightly despite the sad reality.*" (R174, online, C3)

Readers feel motivated to share the postcard and suggest others to further look into the data (n = 50, 23.15%). R185 writes about how the visualizations' style is their main motivation for sharing the postcards: "*[I] would have imagined the numbers differently! [I find that] surprising statistics or beautiful visualizations are more shareable than already known statistics or unappealing visualizations*" [R185, mixed, C5]. Readers in these clusters (C1, C3 and C4) also showed negative feelings on the topics, including feelings of disapproval concerning progress, and considered climate protection as too slow or stagnant. However, they still presented signs of activation when confronting negative messages: "*There is still a lot to do, [we need to] become loud!*" (R135, offline, C3, survey).

On the contrary, in reference to Q1, we found two distinct clusters of readers (C2 and C5) that did not appreciate the format. Readers in cluster 2 showed overall negative engagement with the project. Readers in cluster 5 rated all questions positively but the one about format. Looking at qualitative comments, readers in these clusters were not motivated to share the postcards and were particularly critical. Almost half of the readers in cluster 5, for instance, expressed negative feelings when looking at the visualizations (46%). Common emotions were fear and hopelessness. Readers in cluster 2 also showed negative feelings as well as openly negative commentary. Some readers remarked openly that they would not send postcards to anyone: "*[I would share them] with no one, [because] I find the postcards awful.*" (R74, online, C2). They criticized the way the data is shown, remarking that it is impossible to navigate: "*I would like to see a map with the data. [...] It makes no sense to have to click through hundreds of districts!*" (R12, online, C2). The same negative motif persisted in readers' affective engagement with the topic: comments were often superficial and negative.

Widespread emotional reactions in comments were fear, hopefulness, and preoccupation with the huge task ahead. One reader, when asked which message they would write on the postcard, answered: "*[For what?] 'Save CO2'? They are all hypocrites*" (R140, online, C2).

5.3.2 Channel

In regards to Q2, quantitative results showed that there is no significant difference in the measured engagement between the three channels. Readers from all three settings—online, offline, and mixed—rated the postcards positively along the six quantitative questions. However, answering Q5 through qualitative analysis helped us in spotting differences in affective engagement between channels.

Online There were 78 readers (36.1%), who only used the online version. They often addressed family and friends as addresses of the postcards (n=31, 39.7%). Local people or groups (n=10, 12.8%) and politicians (n=9, 11.5%) were also potential recipients. Readers often felt like other people should see the data (n=31, 39.7%) and were willing to share postcards with them to "start a discussion, [share] my opinion, link to past conversations and to reference them" (R32, online, C1). Overall, 14.1% (n=11) of online readers had a critical tone, both toward content and visualizations. They asked for additional data (n=8, 10.2%) and discussed how the information is represented, in a more critical rather than positive tone: "*I was surprised that there are no more pigs in Braunschweig as of 2016. I would have been interested in how that came about. Possibly small information like swine flu or something like that*" (R2, online, C3). Common emotions expressed in comments are a mix of hope and fear.

Offline The group of offline readers consisted of 105 people in total (48.6%). These readers would share the postcards mainly with friends and family (n=55, 52.4%). As messages, they included generic greetings and addressed individual behaviors (n=39, 37.1%). Sometimes, they cheered for each other, as in the case of one reader greeting a friend for being vegetarian: "*[I would share them with] a friend, [I would write:] 'it is going in the right direction', [because] he is vegetarian.*" (R72, offline, C3). In other cases, they also tried to motivate colleagues and friends to get more informed and active about climate protection: "*[I would write] greetings and ask them to please inform themselves and commit at a regional level.*" (R113, offline, C1). Readers from this group expressed often positive emotions and ideas about climate protection (n=39, 37.1%). They often discussed the possibility of a societal and political shift: "*Public space is far too car-heavy. [...] Create incentives for this so that the mobility transition also succeeds in our city! In our city, car drivers are rewarded with a free 1st hour in the parking garage.*" (R142, offline, C1).

Mixed The 33 readers (15.3%) who looked at visualizations both online and offline tend to be similar to the offline group. They would also prioritize friends and family as recipients of the postcards (n=21, 63.6%) and had an overall positive view of the topic (n=16, 48.5%). R28, for instance, shared their concern about climate protection goals, while keeping a positive and motivated attitude: "*Facts were well presented. Targets are missed completely yet progress is measured. Makes looking away more difficult and motivates.*" (R28, mixed, C1). In this group, more people formulated a call to action (n=18, 54.5%) compared with other groups. Personal calls to action were dominant, readers ask friends to change their behavior (n=5, 15.2%) and political mindset (n=4, 12.1%).

To summarize, the channel of provenance seemed to influence who readers would share postcards with. Across channels, readers prioritize family and friends. Only for readers in the online group politicians and public figures come immediately after. These readers also approach the visualizations more critically than readers from other channels. They tend to address public figures, showing often a disenchantment attitude towards climate protection politics. Offline readers rarely understand postcards as political tools and hold an overall positive opinion on visualizations, both their form and content. They express feelings of hope about political change and appreciate postcards' data and visual style. Readers from mixed channels show a hybrid behavior: they send postcards to family and friends, while calling for action, asking them to change their behavior or continue engaging positively with the topic.

5.3.3 Comparison and localization

As described previously, we specifically analyzed people who used localization and compared different locations, for a total of 75 readers (37.7%). Readers that used comparison and localization features rated the novelty of the visualizations higher than other groups of readers [Q3]. They gave higher scores to the statement "I have learned something new" (Md=6.0). In contrast, readers exclusively looking at Germany postcards (Md=5.0) rated this statement lower (W=3947.5, p=.001). The effect size can only be expressed as weak (r=.18) [56]. Analyzing the qualitative answers for Q6, we saw that readers that used localization and comparison modes were also more likely to produce structured commentary and were mindful of how their experience connects to the data. They often referred to structural political or local change (n=12, 16%), the necessity to do something (n=7, 9.3%), and individual change of behavior (n=4, 5.3%). For example, readers were keen to discuss topics in relation to their area and add contextual information: "*[For] mobility, the data do not describe the actual situation [in Aachen] with public transport (delayed buses with bad connections, inconsistent and poorly structured transit management, etc.)*" (R16, online, C3). This comment exemplified a common pattern among readers comparing information: they often presented critical interpretations about context and content, while also managing to reference their own knowledge. These readers were more likely to see climate protection as a structural problem with grave implications for society and politics (n=12, 16%)). Several times local groups and politicians were mentioned as recipients of the postcards (n=13, 17.3%)). For example, this reader addressed directly their mayor: "*[I would share the postcards] with our mayor. Why does the industry in Heidelberg use 0.0% renewable energies? That does not fit the depiction that Heidelberg is allegedly on its way to climate neutrality*" (R207, online, C3) Readers that took time to compare more regions often looked up their own area. These readers had a more politicized take on the data and drew direct comparisons with other locations in Germany. One reader for instance would share the postcards with both friends and local politicians to express their "*[...] surprise over the great difference between two neighboring districts and Berlin's big task in reaching climate goals.*" (R94, online, C5). Another reader (R43, online, C1) would share postcards with engaged activists and politicians with the following message: "*Take a look at where there are still massive problems in the district*".

6 Discussion

Generally speaking, the results from our case study confirm the need for and value of visualizations carefully designed for constructive climate journalism. By and large, the visualization design goals for constructive climate journalism have helped us in achieving an appropriate and effective design concept. This is corroborated by readers' highly positive feedback in response to the postcards. In this section, we briefly discuss these findings, raise open questions, and suggest possible future research of data visualization for constructive climate journalism.

6.1 Becoming familiar with climate protection

From a design perspective, some of the key affordances of postcards have helped in applying the initially formulated design goals. One good example emerging from the design of the case study is the positive overall reception of the project from the readers. This seems to be linked with the design concept relying on the familar affordance provided by postcards which readers found useful and easy to approach. The playful format and vintage aesthetic of the postcards [DG-hopeful] arguably contributed to readers feeling more hopeful and motivated towards the topic of climate protection. Despite our initial idea of maximizing shareability for political reasons, postcards are rather interpreted as something personal and familiar that can be easily shared with close friends and family. Readers reported a personal connection with the data, addressing people in their closer circle first in their messages.

However, the subjective perception of the style elements also caused negative activation in some readers, when this was the case the content

got quickly dismissed and rated negatively. These readers' comments often read negatively and expressed hopelessness and fear for the huge task ahead. It is possible that by choosing a more neutral concept and aesthetic for the visualizations these negative feelings could have been avoided or mitigated. However, we are inclined to think that since the majority of readers felt activated by the postcards, it would be worth reflecting on tight design concepts for constructive climate visualization. As shown by numerous readers' comments, climate protection is perceived as closer and more familiar, something worth discussing with together with friends and family.

6.2 Comparison and localization: Not popular, but effective

Distributing content in self-contained chunks has been a key strategy to facilitate readers' exploration [DG-access]. Applying this goal to both online and offline content proved challenging—the content needed to be adapted between channels—but rewarding, readers across all channels rated the visualizations as understandable and clear. The collectible nature of postcards supported us in creating more personally relevant visualizations that could span across several locations and sectors [DG-personal]. Still, the majority of readers used neither comparison nor localization features but rather stopped at the national level. The people who did compare between locales or sectors were more likely to address structural dimensions of climate protection. This suggests—considering the multi-level and multi-dimensional nature of the phenomenon—that it might be beneficial to improve comparison features to encourage more readers to make these observations.

When readers took the time and went beyond the first set of postcards, there is the potential for personalization. Personally relevant, local visualizations made readers feel more active towards the topic. They showed a better understanding of the data, maybe because it connected to their personal lives. Personal relevance also seems to increase the perceived novelty: readers looking at location-specific postcards were more enthusiastic about the data. It might be worthwhile to favor localization even more and design data visualizations for constructive climate journalism to highlight from the beginning local and hyper-local portions of the data. This suggestion contradicts the visual information seeking mantra "overview first, details on demand" [57], but it shows that offering a detailed and highly relevant view to readers could motivate them to search for the overview or at least bring them closer to the topic.

6.3 The costs and benefits of consistency across channels

Readers appreciated the self-contained and shareable nature of postcards. They often reported their intention to share them and showed positive feelings of empowerment [DG-share]. Similarly, maintaining the content consistent across channels appears to have facilitated readers' movement across channels [DG-format]: Readers looking at postcards offline or on social media have reported switching to the interactive version. It has to be noted the similar attitudes and reactions when looking at the postcards among readers depending on their channel of provenance. Readers viewing the postcards both offline and online, reported an increased level of activation, i.e., their reported feeling of urgency or the tendency to call out for personal or political change in their messages. This finding would suggest the importance of leveraging a multi-channel approach for data visualization in the context of constructive climate journalism.

In light of the considerable effort to produce consistent visualizations that are channel-appropriate, we are a bit doubtful about the implications of designing for more than one channel. In our case, the offline and social media versions of the postcards ended up being somewhat secondary if compared with the effort invested in developing the online application, which had the most versatility and features. The online application gave readers the opportunity to compare and show localized postcards for all the districts of Germany, while newspaper readers only received a unique set of postcards independently from their location. Despite this, readers from offline and mixed channels showed a very intimate approach to postcards, writing sympathetic yet actionable messages for friends and colleagues. Arguably, offline readers focused concretely on the postcard itself and its affordances. This difference could be used to calibrate climate communication depending on its topic and goal. Would it be possible to design a multi-channel strategy with printed visualizations as the main outcome? Do different channels call for radically different design approaches and design strategies? Future work could explore multi-channel distribution strategies, especially with regard to channel migrations from print to online.

6.4 Limitations

There are several limitations connected with our approach and methodology. First, the channel of provenance is connected with the use of localization and comparison features of the visualizations. In the online version, the readers were able to explore localization by searching for a district, and comparing different locations, which was practically impossible with physical cards. However, readers who encountered the printed postcards had only the option of seeing the visualizations for one or two locales. Comparison was limited to seeing how the respective location is doing in different sectors. This constraint hindered offline readers—especially readers with limited technical knowledge—from comparing postcards more broadly, which may also influence the results of the survey. Running our mixed-method analysis, we rely on survey responses and self-reported engagement from readers. For example, survey participants were asked to whom they would send the postcards, we have no knowledge about the sharing activities of this kind, especially when done as private communication. This is connected with the kind of analysis we were able to do. The use of short survey answers to study affective engagement is limited. Future studies could consider fewer participants or further data collection iterations, but using more in-depth methods such as interviews, focus groups, and structured workshops to expand our understanding of readers' emotional reactions to constructive climate visualizations.

Lastly, our research focused on the consumption of visualizations by readers, by proposing audience-centered design goals and studying readers' responses. Future work could look into the production of constructive climate journalism, and how to support journalists to make sense of and structure highly complex and multi-dimensional data. The creation of authoring systems and strategies would be essential to scale up the reach of constructive climate journalism.

7 Conclusion

At the beginning of this research, we speculated how visualizations could be designed for constructive climate journalism and if they could have the potential to render intrinsically complex topics such as climate protection more approachable for readers. In order to devise an approach to data visualization for constructive data journalism, we have identified three key challenges of climate communication—multiple sectors, levels, and channels—and formulated five concrete design goals for approachable and actionable data visualizations to be used in constructive climate journalism projects. Following these domain characteristics and design aspirations throughout the design study, we iteratively translated the design goals into the concrete design decisions. We developed the design of the visualization postcards with the fundamental idea of promoting readers' shift from negative emotions of climate anxiety to positive feelings of realistic hope. Finally, we reported on readers' affective engagement with the visualizations of climate protection in different settings and across channels. Our findings from readers' feedback confirmed the viability of this overall approach. We hope this research will motivate visualization scholars and practitioners to expand this approach to other complex topics of constructive data journalism, e.g., biodiversity loss and water scarcity. Expanding our knowledge about the capacity of data visualizations to support readers' affective engagement with complex issues can enhance public engagement with the difficult and urgent challenges of our time.

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