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Connecting audiences with climate change: Towards humanised and action-focused data interactions

Marta Ferreira *, Nuno Nunes, Pedro Ferreira, Henrique Pereira, Valentina Nisi

I.S. Técnico, Universidade de Lisboa, Lisboa, Portugal

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ABSTRACT

This paper investigates the relationship between design research and humancomputer interaction (HCI) in the context of climate change communication and engagement. We discuss current practices in climate change communication and the decrease in concern and engagement caused by "crisis fatigue". Through Research through Design (RtD), we set out to investigate data humanism and how users react to climate change data, testing approaches to improve engagement. With this purpose, we designed and evaluated *Finding Arcadia*, an interactive data story that uses data humanism to shift the dialogue from crisis-focused to action-focused. One study with the original IMF visualisations ($N = 17$) and two studies in public spaces ($N = 12$ and $N = 64$) point to the contextualization of the data and presenting actionable solutions helping in engaging users with climate change issues; help in creating solution-focused narratives and interpreting and relating with climate data. From these results, we derive insights for designing empowering interactive data visualizations for resilient climate change engagement.

1. Introduction

Climate change is one of the most significant challenges we face today. Communicating about climate change is fundamental to mobilizing action, countering misinformation, and conveying a helpful message that empowers and motivates people to engage. Just recently, the UN recognized the importance of communicating climate change by establishing guidelines (U. N. D. of Global Communications 2022) centred on three main areas: i) use authoritative scientific information; ii) convey the problem and the solutions; and iii) mobilize action. These guidelines reinforce the importance of positive engagement, storytelling, personalization, and presenting solutions to work towards empowerment and counter "crisis fatigue" – when prolonged exposure to unexpected and stressful events leads to burnout (Coelho, 2020).

Climate change is an increasing concern in Human-Computer Interaction (HCI) and design research (Ferreira et al., 2021; Mencarini et al., 2023; Williams et al., 2022; Doggett et al., 2023). Sustainable HCI (SHCI), in particular, focuses on enhancing human well-being while minimizing environmental impacts (DiSalvo et al., 2010). One initial approach was to argue for SHCI research to articulate clear or design specific sustainability goals and metrics on a project-by-project basis (Silberman et al., 2014). Later, Knowles et al. asserted that we could better pursue cohesion by establishing a sound understanding of sustainability that could bring the community together (Knowles et al., 2018). One of the takeaways was that we should orient HCI work around climate change rather than the more broadly multidimensional concept of "sustainability". The rationale stems from Klein's premise that climate change provides a much-needed coalescing narrative that does not distract us from the existential urgency (Klein, 2015).

However, there is increasing evidence of "crisis fatigue" – a phenomenon where people become overwhelmed and desensitized by repetitive exposure to negative events and related emotional framings, which leads to decreased concern and public engagement (Beehler, 2019; Flinders, 2020; Bloodhart et al., 2019; Feinberg et al., 2011; O'Neill and Nicholson-Cole, 2009). Hence, an increasing number of studies point to the need for communication strategies that don't focus only on negative framing, but consider action and feelings of efficacy (Hart and Feldman, 2016; Doherty and Webler, 2016; Feinberg et al., 2011; Corner et al., 2018), personalization and emotional connections (Gustafson et al., 2020), adaptation to diverse audiences (Chapman et al., 2017) and create a sense of hope and possibility (Ojala, 2012; Ojala, 2022; Stern, 2012).

In this article, we argue for the potential of *data humanism* to provide a general framework for prioritizing the ethical and human values in the

* Corresponding author.
E-mail address: amartaferreira@tecnico.ulisboa.pt (M. Ferreira).

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design and interpretation of climate change data(24). Data humanism, proposed by information designer Giorgia Lupi in a manifesto (G. Lupi, 2017), is a philosophy in data processing and visualization that prioritizes human needs and values, advocating for individualized and nuanced perspectives while emphasizing context and personal experience over traditional infographics. Following this approach, data should be communicated alongside storytelling and relatable metrics that give meaning and context to the numbers. We propose that this design approach can be used to make the science of climate change accessible and engaging to a broad audience, aligning with UN's guidelines: "*Presenting data alone may numb the audience. Make it relatable, local, and personal* " (U. N. D. of Global Communications 2022).

We contribute to climate change communication in HCI by presenting Research through Design (RtD) (Zimmerman et al., 2010) project that explores how data humanism can engage audiences with climate change data in a personalized, contextualized, and action-focused way. Our project takes the form of an interactive data-story (Fig. 1) that communicates ocean-related data based on International Monetary Fund (IMF) research (Chami et al., 2019). The study evaluates how this visualization approach can foster positive and empowering interactions with climate change data. To achieve this, we focus on three research questions: a) If and how users feel connected to the humanized data; b) If the humanized data affords users a positive outlook on climate change; c) If solutions-oriented visualizations create a feeling of empowerment and agency towards climate matters. Moreover, we discuss the results from the application of the novel Data Humanism design approach (Ferreira et al., 2023), and derive implications for future HCI and design research in climate change communication.

The rest of the paper is organised as follows: first, we present the related work around communication and engagement with climate change topics. Secondly, we present the design and implementation of the *Finding Arcadia* project, which is based on data humanism principles. Thirdly, we report on the studies performed. The study's results highlight how users are aware and concerned with climate change, how their behavior can make a difference, but also how governing institutions play an important role. Regarding the data humanism strategies, results show that the storytelling strategy helped in giving meaning to the data "abstract" numbers. Moreover, the unfamiliar topic (whales as a carbon-capturing solution) effectively engaged users. Finally, linking the story to action was seen as useful but was not sufficient to significantly shift the established negative framing associated with climate change.

We conclude by discussing future directions, pointing to the need to add context to climate change data, how the solutions-oriented data-story helped in giving users a sense of agency, and simultaneously, the challenge of countering the negative framing associated with climate change. This discussion led to insights for future work in HCI and Design for action-focused interactions with climate change data.

2. Related work

This research builds on prior work in climate change communication and SHCI. In the following, we summarise i) recent discussions and proposals regarding climate change communication and how the HCI and design research communities have been addressing this topic, ii) HCI projects that embrace a *data humanism* approach, and iii) Recent HCI approaches connecting users with data.

2.1. Interacting with climate change data

2.1.1. Climate change communication and engagement

Communicating climate change is highly complex. The scale of the problem, which demands widespread citizen participation and systemic change (IPCC 2018; Wuebbles et al., 2017), means that a multitude of data needs to be conveyed, together with the urgency of the problem and the underlying science. The impact of this data depends on how the information is imparted. The debate around climate change message framing is ongoing, and studies on the efficacy of different communication strategies have returned mixed results. Some studies point to fear-inducing messages causing stronger reactions when compared to hope (Hornsey and Fielding, 2016) while other studies report inducing fear not having a significant effect on climate change risks perception (Ettinger et al., 2021). Other scholars highlight that the simple reframing of the message (e.g. changing the discourse on sustainability efforts from their benefits for climate change mitigation to other types of benefits such as innovation, health benefits, or community building) is unlikely to increase public support (Bernauer and McGrath, 2016). On the other hand, evidence demonstrates that fear is ineffective in motivating personal engagement with climate topics, but it can attract people's attention (O'Neill and Nicholson-Cole, 2009). Another study calls attention to people's preference for messages framed without emotion, rather than through negative emotions (Bloodhart et al., 2019). For (Feinberg et al., 2011; Hart and Feldman, 2016; Doherty and Webler, 2016), solution-oriented messages seem to assist in the perception of efficacy and engagement, pointing to the importance of linking communication to action (Doherty and Webler, 2016). A positive frame reinforces public support (Dasandi et al., 2022) and *hope appeals* can be a powerful tool to be harnessed in persuasive communication (Chadwick, 2015). On a similar note, guidelines for climate change communication have pointed to the importance of framing the interaction positively to avoid a "feeling of hopelessness" (Corner et al., 2015), as a narrow narrative focusing exclusively on "doom and gloom" leaves the public feeling powerless (Arnold, 2018). Reporting the impacts of climate change exclusively portrays an incomplete view of society. Stories about constructive problem-solving, for example, are often neglected. Climate change must be presented as solvable (Mayer and Smith, 2019), shifting the focus from assumed sacrifices to what becomes possible (Tonkinwise, 2011). Data needs to be presented in a relatable way, using stories besides graphs and statistics to connect it to what matters to that

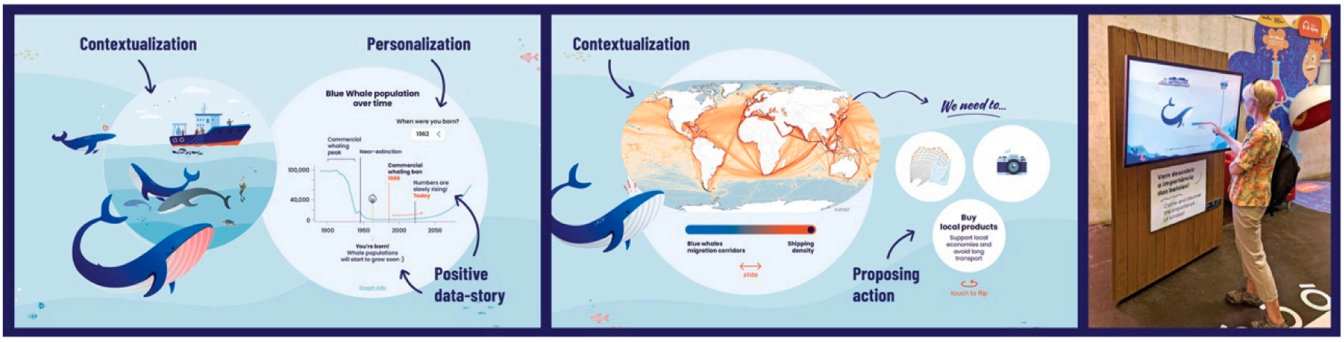

Fig. 1. Two screens of the data-story with captions of the data humanism aspects explored, and the installation in the science museum (pilot study).

audience, including solutions in the narrative (Chapman et al., 2016; Corner et al., 2018). Personal stories can be a persuasive communication strategy to engage diverse and even sceptical audiences (Gustafson et al., 2020). A wider selection of narratives is needed (O'Neill et al., 2015). Because of its complexity and potentially polarising nature, climate change interactions cannot depend on single, universal engagement strategies. (Chapman et al., 2017) suggests an audience-focused approach based on *message tailoring*, focusing on the individual's particular needs and avoiding a "one-sizefits-all" approach. HCI has already explored strategies to support more complex forms of communication. Moving forward, we must operationalize methods in adaptable, engaging, and structured approaches for climate change-related interactions.

2.1.2. Interactions with climate change in HCI and design research

A recent survey based on the past decade of HCI and design research concluded that most interaction design projects provide a neutral message, i.e., they communicate through a neutral framing based on examples and data visualizations, with no suggestions for action (Ferreira et al., 2022). This is consistent with mainstream media's "pragmatic" data communication strategy. This study points to the opportunity of choosing less explored and less-known topics, including more inclusive perspectives such as i) taking the communication activities to daily-routine places and therefore engaging users "where they are"; ii) proposing actionable steps as part of the interaction, supporting positive framing and feelings of agency; and iii) adapt the message to the particular audience you are engaging with. While addressing this research, we followed these guidelines to promote inclusive and action-focused climate change interactions.

Climate change is a fast-growing topic in the HCI community, and the communication and interaction strategies employed are diverse. Applied research has looked into leveraging the impact of emotions and a sense of community to communicate climate change topics (Aragón et al., 2021). Besides engaging local communities in critical discourse, it successfully links to action through connecting to local organizations and services (Paraschivoiu and Layer-Wagner, 2021). Through this research, the authors engaged with the importance of playful and location-based experiences, recognizing how long-term engagement is challenging, especially with people who are not interested in sustainability (Paraschivoiu and Layer-Wagner, 2021). In the home context, environmental awareness related to users' behavior has been tested through a data sculpture (Stegers et al., 2022), highlighting the importance of personal and group data for deeper understanding and the challenges of communicating complex information. Still, there was no concrete information on the impact of the sculpture on users' further actions or reflections on the climate change topic.

The importance of how environmental data is sorted and framed (highlighting certain attributes of items) has been shown to affect energy-saving decisions (Starke et al., 2021). Another influencing factor is personalization, which can lead to enhanced data engagement through familiarity (Van Den Bosch et al., 2022).

These projects demonstrate the plethora of strategies focused on climate change action, relation to the community, or how the data is presented to a particular audience, highlighting a timely and rich arena for investigation. However, to our knowledge, no other research project has combined HCI with a focus on positive framing, data humanism, and climate change data engagement, furthering Ferreira et al. (Ferreira et al., 2022) guidelines and implications. Our study focuses on the efficacy of such communication strategies in informing future HCI climate change communication work.

2.2. Data humanism

2.2.1. Data visualisation and a shift towards humanisation

There is little agreement on the best way to visualize complex data for lay audiences (Meloncon and Warner, 2017). Leading authors on data visualization from the past three decades have greatly focused on the efficiency of design and clarity of communication in what can be categorized as a "neutrality" principle (Zhao and Sun, 2022). Tufte proposed a distraction-free approach focused mainly on presenting the actual data and avoiding *chartjunk* (Tufte, 2013). Others have pointed to the importance of accuracy and clarity for effective and efficient communication (Few, 2012) and warn against the persuasive misuse of data visualizations (Cairo, 2016) or suggest following applied human perception (Ware, 2021). This leads to the storytelling approach summarized by McCandless: information (data), story (concept), goal (function), and visual form (metaphor) (McCandless, 2014). Storytelling gains greater relevance in data visualization design, marking a shift from neutral to humanistic representations. It also embraces ambiguity and complexity, contrasting the claims of information being value-neutral or observer-independent (Drucker, 2011). In 2016, Lupi proposed a paradigm shift in how we represent data, moving away from impersonality and questioning "truth" and simplicity principles. Named data humanism, the approach encourages the audience to slow down, explore, engage with, and appreciate the visualization (Richards, 2022). Lupi has formalized this call in a manifesto that encourages information designers to: 1) *Embrace complexity* – move away from the need to keep visualizations as simple as possible, allowing for layered communication; 2) *Move beyond standards* – create customised designs for the specific data being worked; 3) *Sneak context in* – consider subjectivity and context; and 4) *Remember that data is imperfect* – data is "human-made" and, therefore, does not represent a "universal truth"; research and translation can help in understanding (G. Lupi, 2017). The purpose is to create engaging and personalized data-driven visual narratives that link the numbers to what they stand for – stories, knowledge, people, and behaviors (G. Lupi, 2017; Lupi, 2018) – by adding qualitative information that supports contextualisation and meaning. This method opens opportunities for designers to be more creative and look beyond the standard chart types, inspiring alternative human-data interactions. There is an emphasis on user participation, leading to an emotional experience that relates to humanistic qualitative information, not just quantitative (Zhao and Sun, 2022). Emotion is crucial in building memories and making meaningful decisions (Immordino-Yang and Damasio, 2007). Strategies that allow appraisal of information in rational but also emotional ways are essential (Canossa et al., 2022).

Data humanism uses data as a tool that allows for reality to be imagined and understood, as data is a partial and subjective representation of reality, dependent on how it is collected and selected (Ippoliti et al., 2020). Visual depictions facilitate the interaction between individuals and their social and political realities (Piron and Paraguai, 2019). Zhao and Sun (Zhao and Sun, 2022) discussed recent aesthetic strategies in information visualization with a significant focus on "humanising" data. They point towards "conceptual speculation" to move beyond the established "empirical induction" by: a) embracing *emotional experiences* – emphasising emotional aspects of the data to trigger reflection; b) using *visual metaphorical rhetoric* – the importance of metaphors to highlight points of view; c) that *speculative design catalyzes social dreams* – stimulate thinking about dreams and values that can lead to changes in behavior. For example, data representations that raise awareness for sustainable behaviors on university premises have used comparisons of distances to make the vast numbers more comprehensible, in line with data humanism principles (Ceccarini et al., 2023). Making data contextual and intimate (G. Lupi, 2017), and therefore *"reconnected to our lives and our behaviors"* (Lupi, 2018), align with recent communication guidelines for climate engagement: *"Presenting data alone may numb the audience. Make it relatable, local, and personal"* (U. N. D. of Global Communications 2022); and with Meloncon and Warner's (Meloncon and Warner, 2017) opportunities for future work derived from their literature review on data visualisations: an emphasis on contextualisation and context awareness, and allowing users to select more personalised data to display through the use of interactive displays. Therefore, data humanism's conceptual and formal strategies

present a promising response to the challenges in climate change communication discussed in 2.1.1.

2.2.2. Data humanism in HCI research

Data humanism comes into HCI research as one of the most recent contemporary perspectives on data visualization, enabling a shift of data ownership towards people, embedding data in everyday experiences (Ferreira et al., 2023).

Data humanism, in particular, the Dear Data project (Lupi et al., 2016), has inspired researchers to test its blend of data exploration and hands-on approach to assist in data literacy (Byrd, 2021; Krekhov et al., 2019) broadening users' notion of what data could be and the multitude of ways it can be visualised. "Data selfies" are now standard (e.g. in dating or exercise apps), representing oneself through data, and can lead to self-reflection and discussion (Robards et al., 2021). Data humanism arguably takes these self-expressions one step further. Two studies inspired by *Dear Data* focus on personalization by creating custom visuals (Kim et al., 2019; Romat et al., 2020), leading to deeper engagement and enjoyment. Nevertheless, these representations face the challenge of balancing readability and aesthetics. The possibility of creating more complex and unusual data visualizations necessarily requires more availability from users. The design of impactful, metaphor-based visualizations can educate and communicate several layers of information simultaneously (Angulo et al., 2020).

Humanising strategies were used to propose a hybrid data approach that enhances the meaning of quantitative urban IoT data, by adding layers of context-specific qualitative data (Houben et al., 2019). Similarly, a layered design that combined "abstract and numerical" feedback about daily behavior raised environmental awareness and facilitated reflection (Sauvé and Houben, 2022).

Research points to the potential of data humanism to support deeper data connections and data understanding through diverse, playful and enjoyable explorations (Kim et al., 2019; Krekhov et al., 2019). These projects highlight the importance of connecting lay audiences with data through less "neutral" and more engaging approaches, countering research's typical focus on limited visualization types (Meloncon and Warner, 2017). The HCI community has been debating its role in building more sustainable futures, including in *"making data understandable, usable, and actionable"* (Mencarini et al., 2023). However, to our knowledge, no other HCI research has tested data humanism in climate changerelated visualizations. Building on previous work, we set out to understand if data humanism – focused on personalization, contextualization, and connecting to action – fosters positive and empowering interactions with climate change data.

2.3. HCI approaches connecting users with data

Engaging users with data in "new ways" is not a novelty in HCI research, and some approaches share methods or intentions with data humanism. Storytelling has long been used in data representation to enhance visual expression and assist in conveying meaning (Rodríguez et al., 2015). Using strategic interactive elements along the story for user exploration of the data has been mentioned as an effective strategy for engagement (Segel and Heer, 2010). This interactivity can add contextual, "humanising" layers to the data. Regarding environmental data, eco-feedback experiences are a popular method of materialising energy and other sustainability-related data, especially in the home (Barreto et al., 2014; Pereira and Nunes, 2020) or community (Bird and Rogers, 2010) settings. These projects have a personalization component that responds directly to user behavior. Also related to sustainability, projects such as the *Indoor Weather Stations* (Gaver et al., 2013) or *Energy Babble* (Gaver et al., 2015) have worked towards the physicalization of environmental data. When exploring *how* the users engage with the data, data physicalization (Jansen et al., 2015), sometimes called physical visualisations (Jansen et al., 2013), helps people to explore and understand data through physical representations (Hogan and Hornecker, 2012). Similarly, tangible user interfaces (TUI) allow users to interact with digital information through physical artefacts (Holmquist et al., 2019; Ullmer and Ishii, 2000). Like data humanism, data physicalisation and TUIs explore alternative data presentation formats that frequently demand more user attention but can also lead to deeper engagement. These strategies can engage larger audiences with complex data, especially in public spaces (Hornecker and Buur, 2006), as people tend to spend time and effort exploring the experience (Jansen et al., 2015; Bae et al., 2022). Likewise, these approaches to data can be highly subjective because of the need to select and translate data into these physical forms (Waldschütz and Hornecker, 2020). Still, they can help elicit affective responses, reflection, and memorability.

Another strategy that can be conceptually linked to data humanism is adding context to the data and enhancing relatability through connection to location. "Situatedness of use" has been explored by bringing outside data inside the home (Gaver et al., 2008), while location-awareness was used to relate users with "big data" about the areas they are in (Gaver et al., 2016). These approaches are examples within HCI that work towards connecting users to somewhat abstract or complex data, bringing it to everyday settings.

Data humanism shares characteristics with these established HCI fields. However, we argue this approach can contribute to new venues within HCI data visualisations, especially within complex and polarising topics like climate change. Data humanism avoids over-simplification and focuses on aesthetics, exploration, storytelling, and a deep connection to emotional and personal value. It can be leveraged in developing more inclusive perspectives – not only in "humanising" complex data, mainly related to sustainability but also in creating meaningful non-anthropocentric connections (Akama et al., 2020; Forlano, 2017; Light et al., 2017) within complex data sets.

3. Research prototype: *finding arcadia*

Derived from the challenge of engaging users with more accessible and actionable data visualizations, the research reported in this paper sets out to understand: a) If and how users feel connected to the humanized data; b) If the humanized data affords users a positive outlook on climate change; c) If solutions-oriented visualizations create a feeling of empowerment and agency towards climate matters. To address these research questions, we started by summarising data humanism principles (G. Lupi, 2017) into a formalised design approach (Ferreira et al., 2023). This paper contributes to the first studies of the Data Humanism design approach.

3.1. Development approach and design decisions

The research prototype was developed following RtD (Zimmerman et al., 2010). First is the Grounding stage. We discussed related work and performed a systematic review of projects (Ferreira et al., 2022), pointing to the importance of focusing the message on action, taking the interactions to "where the audience is", engaging audiences with less explored and exploited topics, and presenting alternative and more inclusive perspectives – including the perspective of other species and the importance of cohabitation (Kobayashi, 2014; Smith et al., 2017; Mancini and Lehtonen, 2018; Light et al., 2017). Our design decisions worked to address these gaps, and looked at "a broader suite of solutions" (Wilkinson, 2020), including natural sinks (land, coastal and ocean). In this direction, a recent International Monetary Fund (IMF) report (Chami et al., 2019) describing whales as one natural solution for climate change mitigation – i.e. each great whale sequesters 33 tons of CO2 on average (Chami et al., 2019). This study had great coverage in mainstream media (e.g. (Stone, 2019; Yeo, 2021; Randow, 2019)) and was accompanied by visualisations, presenting an opportunity for visual analysis.

The following stages in RtD are *Ideation* and *Iteration*. During the ideation stage, the authors debated possible media outputs,

implementation locations, stories and character journeys. We settled on an interactive data humanism story installation to bring the data to diverse audiences in a public location. Therefore, through five design steps (Section 3.2) we designed the data-story centred around a main character, Baltazar, the Blue Whale (3.2 – DH.2).

After completing the first story draft, we conducted four online co-design sessions with entertainment and HCI experts to refine the narrative and a session with a marine biologist to validate the scientific data. In these sessions, the first author presented the data-story through the sketched storyboards and narrated the audio content that would be used for each section of the story. She would then take notes on the suggestions presented by the experts. Changes from these sessions include refining the whale data used (e.g. being mindful of the lack of scientific consensus on some aspects of the biology and behavior of marine mammals), changes to the story structure to include a tighter and more dramatic plot, changes to the user input strategy (having input fields next to each visualisation instead of asking all the information in the beginning of the experience). The final version of the prototype underwent further validation through a pilot study described in Section 4.1.3. The final iteration of the study was used in the main study, described in Section 4.2 of this article.

3.2. Prototype overview and applying data humanism

Data humanism proposes connecting the data to qualitative information, allowing for contextualization and personalization. This approach hopefully makes the data more relevant to users. To operationalise *data humanism*, we derived five steps from Lupi's propositions (G. Lupi, 2017; Lupi, 2018) and proposed a novel Data Humanism design approach (Ferreira et al., 2023).

In the following, we summarise the main design decisions related to the five steps derived from the data humanism approach (Fig. 2 and 3). A detailed description of the design decisions can be found in (Ferreira et al., 2023).

- **DH.1.** ***Frame the question that triggered the data exploration:*** our focus is on communicating oceans as crucial for global climate through the ocean carbon cycle data (Chami et al., 2019), and whales as a fundamental part of the ecosystem (Johnson et al., 2022), as well as connecting the data to people's lives.
- **DH.2.** ***Discover what is unique about the data:*** We strived to create empathy through the whale story, highlighting cohabitation and lessknown natural solutions. The ocean and whale CO2 cycle data, along with other environmental data, is communicated through the original story of Baltazar, the Blue Whale (Fig. 2 and 3), and his adventures as he navigates the oceans in search of Arcadia, a special place his mum took him as a child. Along the way, he explains the CO2 cycle and also confronts the consequences of the Anthropocene, such as plastic pollution, the consequences of whaling, or shipping density.
- **DH.3.** ***Define the story to communicate through the data:*** We crafted a positive but accurate story centred around the whale life cycle. Attention was focused on the positive framing of the climate change topic, e.g., showing the dramatic numbers caused by decades of commercial whaling while calling attention to the slow but exponential rise after the international whaling ban (Fig. 2-1). We also communicated resilience and hope by ending the character's journey naturally, and this was not caused by the dangers he faced (Fig. 3-6). Another crucial aspect was closely connecting to action throughout the story, underpinning the idea of "hope" and giving a sense of agency. We proposed solutions related to each section's topic (Fig. 3-5) – e.g., related to plastic pollution: "Look for natural fibres" or "Buy veggies and fruit not wrapped in plastic"; related to ship density: "Buy local products" or "If you do tourism in the sea, make sure it's with a certified company"; or linking to CO2 emission reduction: "Reduce food waste" or "Buy less stuff".
- **DH.4.** ***Provide meaning and context to the audience:*** Throughout the story, data was contextualised to assist in interpretation. The data was communicated through the story of one particular (*humanised*) whale, connecting the data to sections of Baltazar's life. Furthermore, the climate change data is accompanied by layers of "qualitative data" (comparisons to more familiar metrics and situations), including actionable solutions. Examples of this are the carbon cycle and whale carbon/oxygen flux, where we add additional information or compare the data with more approachable information – CO2 absorbed by phytoplankton compared with trees, with CO2 emitted by countries the user can choose from, adding elements for size comparison, etc. (Fig. 2-3).
- **DH.5.** ***Humanise the data:*** We conceptualised strategies that allowed for personal customization of the visualisations. To help the audience relate to the data, we enriched the visualizations with personal layers of information from the user's input, adapting to, for example, their date of birth, height, or country (Fig. 2-2). We also added climate change information related to the Tagus River (Fig. 3-4), as this community has a profound social and historical connection to fishing, navigation, tide milling, and other river activities.

4. User study

This section describes the goals and measures used in the prototype testing and explains the context and protocol used to examine the research questions. Finally, we detail the data analysis and results.

Our study process included a baseline study with the original IMF data visualizations and two "in the wild" studies with our interactive data-story (Fig. 4). We set up the interactive story to be experienced through a touchscreen display, where users could interact directly with the data visualizations (Fig. 5). The screen was placed in a triangular module made of recycled plastic – one face supported the screen and two other faces where equipped with tangible elements that users could engage with and leave their feedback on – one face allowed users to leave feedback about the story by answering two questions with coloured dot stickers, and the other face encouraged users to leave messages through post-its (Fig. 5b).

Since the installation was placed in public locations and the purpose of the study was to engage diverse publics through the chosen contexts of implementation, there was no previous recruitment of participants. Passersby were casually approached for participation. Before replying to the anonymous questionnaire (no personal data was collected), participants received an overview of the study, emphasizing that the evaluation focused on the artefact rather than on them personally, that they could withdraw at any time, and could ask any questions to the researcher. The participants of the follow-up interviews were asked to sign a consent form containing the study information, along with the researcher's contact details, as this part of the study was not conducted in a public context. This study involved only adult participants (over eighteen years old) with no specific population focus. Apart from age, there were no other disqualifying criteria.

4.1. Pilot experimental study

During the five-day UN Ocean Conference, we conducted the pilot study in a major science museum in the city of Lisbon. The pilot was meant to test the data-story, understand its appeal to various audiences, and pilot the interview protocol.

4.1.1. Methods

The installation was placed inside the museum in an area accessible only to conference visitors and then moved to a passage location for two days accessible to all visitors (Fig. 5-a). Three researchers (the first, third, and fourth authors) were involved in the study. All three took turns noting observations and engaging with users to conduct the user interview.

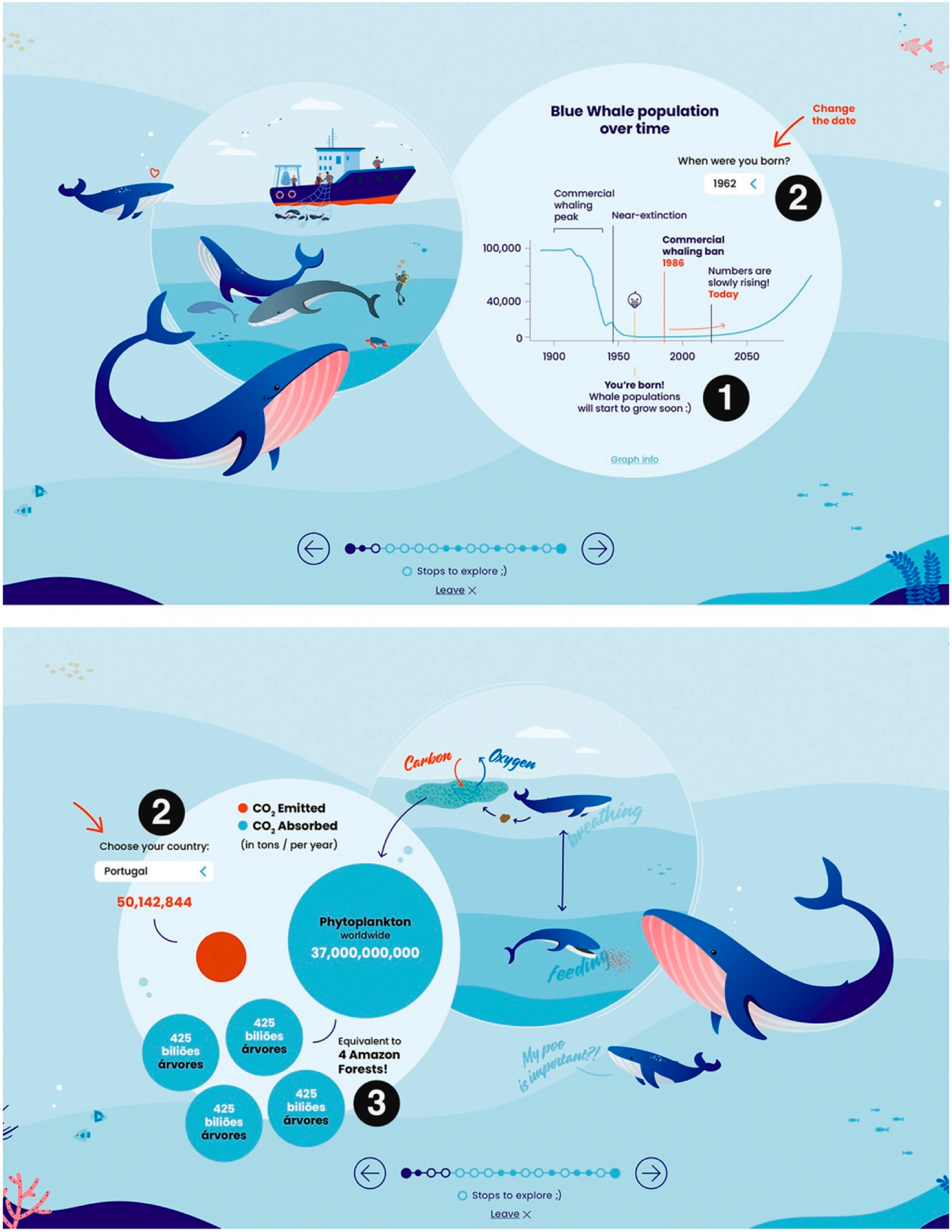

Fig. 2. Sequence of screenshots from the interactive visualizations that summarise Baltazar's story, complete with the data humanization: (U. N. D. of Global Communications 2022) Give a positive spin to the narrative; (Coelho, 2020) Allow the user to personalize the visualization; (Ferreira et al., 2021) Contextualise the data by comparing and adding layers of "soft" (qualitative) data.

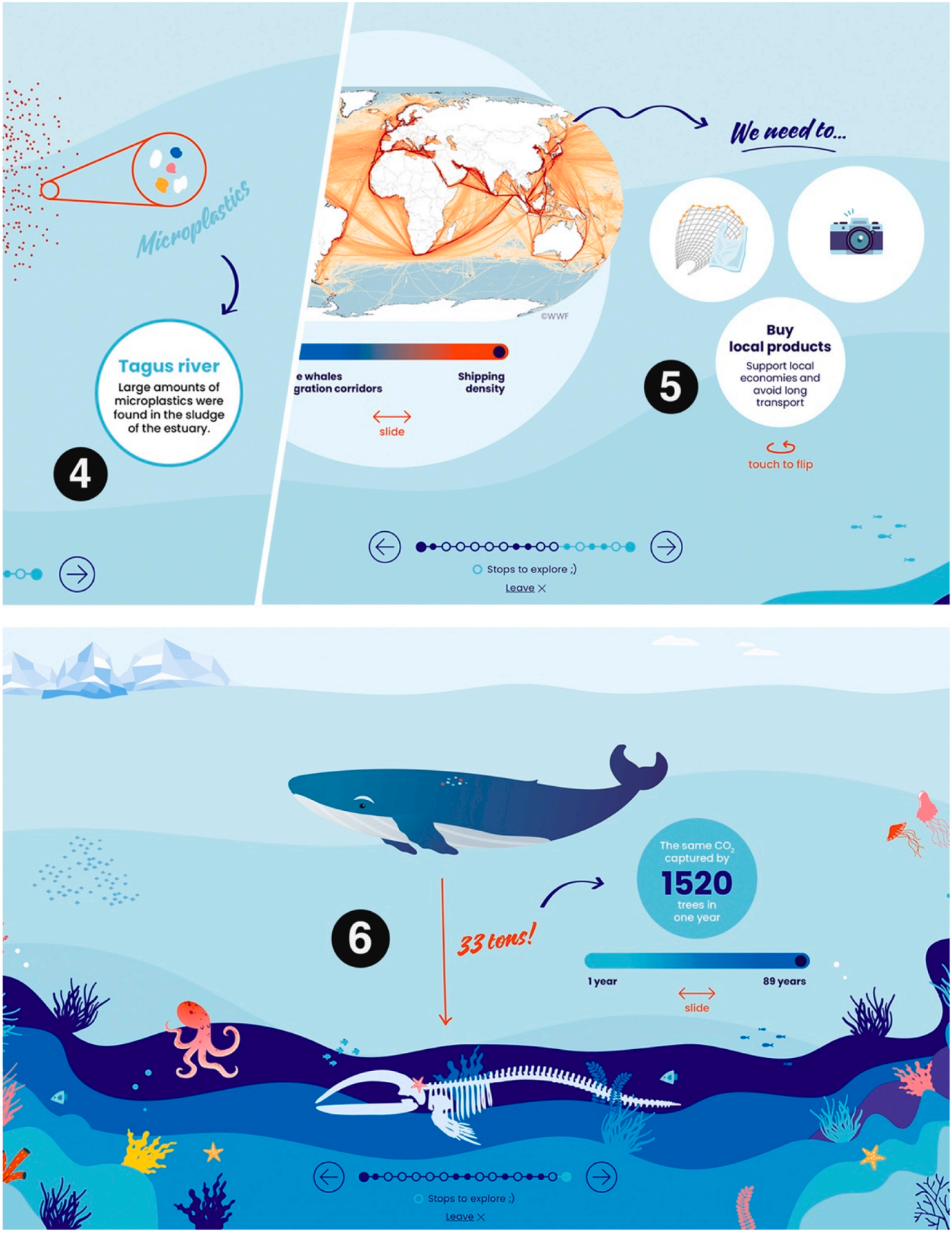

Fig. 3. Sequence of screenshots from the interactive visualizations that summarise Baltazar's story, complete with the data humanization: (Mencarini et al., 2023) Make the data relatable to this particular community; (Williams et al., 2022) Focus on action by proposing solutions; (Doggett et al., 2023) Design the character journey as resilient.

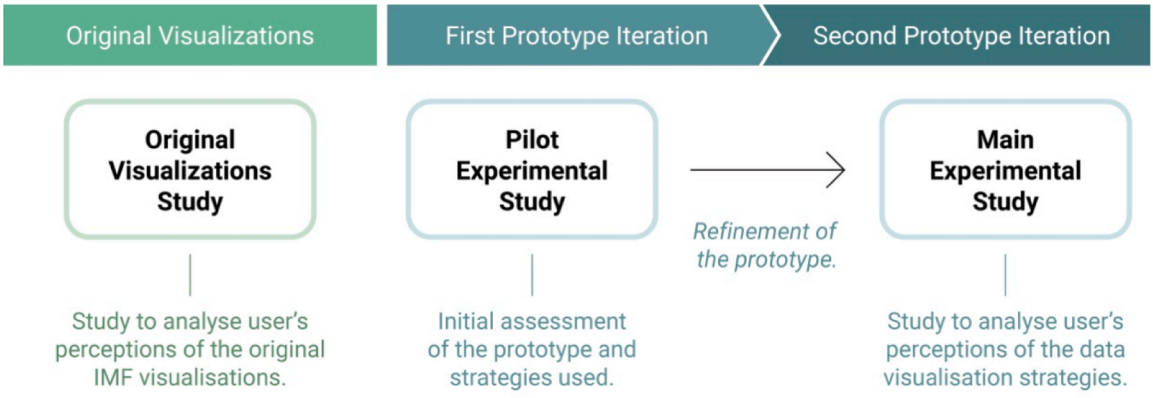

Fig. 4. Scheme of the different study phases and their purpose within the overall research.

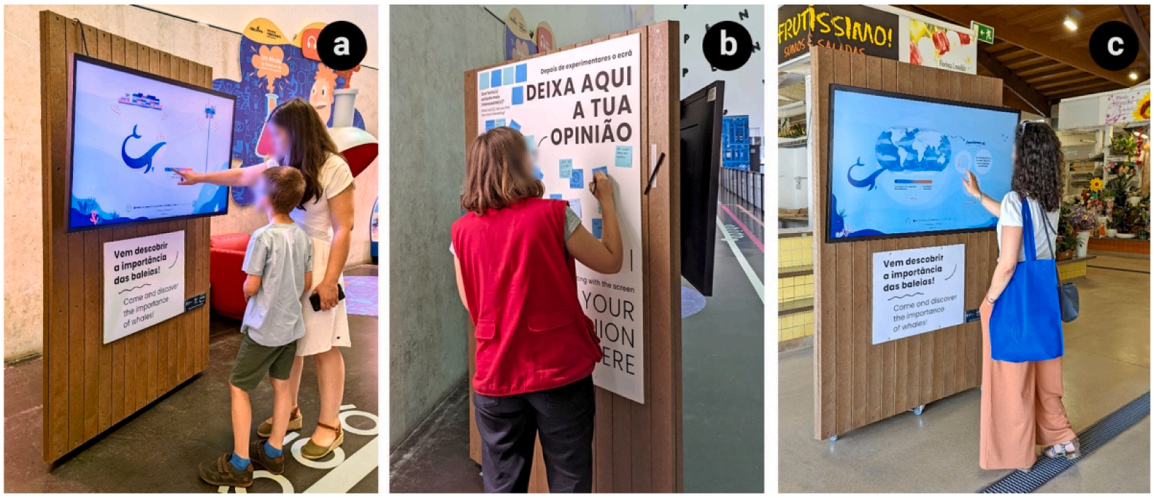

Fig. 5. Deployment of the prototype: (a)(b) Pilot study in the science museum; (c) Main study in the local food market.

During the five days of implementation, observations were noted regarding the user's stance, attitude, and comments towards the installation in general, and the data-story interactions in particular. The researchers observed at a distance and allowed users to start the activity alone. After the interaction, the researcher approached users, explained the purpose of the study, and asked if they could answer a brief anonymous interview based on four demographic questions and six open questions, which included: "Before this experience, did you associate climate change with the oceans? And with whales?"; "What did you think of the way the information was presented?"; "Do you think the information presented is relevant to your life?"; "How did the story make you feel?"; "Did the story inspire you to take action? How?". We gathered twelve user interviews (P1 to P12).

4.1.2. Participants

To understand better how adults deal with the negative communication around climate change and crisis fatigue we focused our study on adults (over 18 years old) – young adults (aged 18-34): n=3; adults (aged 35-64): n=7; senior adults (aged 65-74): n=2. Regarding gender, n=7 identified as women and n=5 as men. All twelve users were educated at the undergraduate level or higher.

4.1.3. Results of the pilot study

From the results of the pilot study, the prototype was refined. The main improvements are described below:

- Longer sections of the story without interactive elements (only with visuals and narration) made users disengaged. The interactive features (e.g., buttons, sliders, and clickable components) promoted engagement and understandability of the data: *"It helped to understand. (…) The interactive elements helped to contextualize. It's not so dense."* (P12).
- Some users thought the information was helpful for them and for society in general. Some commented that the solutions proposed were not actions they could do themselves, hence disconnected from their everyday lives (e.g., related to public policy): *"The solutions specific to the oceans are not so actionable. Other things like the ships, you can only ask for government action."* (P7); *"I can't have much impact in these matters."* (P10);
- Participants highlighted that proposals for action provided a more positive framing of climate change. However, some positive data (e.g., the whale population numbers rising) and the perceived negative and overwhelming general topic of climate change provided a certain cognitive dissonance: *"Happy to know whale numbers are recovering."* (P1); *"More the perspective of the future, trying to help. Focus more on action than on the negative."* (P5); *"I felt a bit defeated because I feel there isn't much I can do but felt good because I saw some things are getting better. Like the increase in whale numbers."* (P7); *"It added information. It was nice seeing the whale numbers going up. That's a positive thing. The info about ships and the noise depresses me because I don't see a quick solution."* (P9).

4.1.4. Refinement of the prototype for main study

The outcomes of the pilot led to several revisions in the prototype:

- The story was shortened to make the experience more concise;
- More interactive components were added to the visualizations, allowing further personalization and humanization of the data;
- Some of the proposed solutions were refined to better appeal to the audience that wanted to be able to act upon them, and
- We refined the evaluation protocol, adopting an evaluation survey based on a Likert scale and further open questionnaire, for more varied data sets and a more straightforward approach in the wild.

The audience engaged in the pilot study also informed the placement of the main study, as we wanted to reach a more diverse group of users.

4.2. Main experimental study

We decided to implement the main study in a local food market in the city of Lisbon to cater to a more diverse population of non-experts. As Emily Dawson has shown, low-income and less formally educated groups experience exclusion from spaces of informal science education, such as science museums, often considering that those spaces "are not for them" (Dawson, 2014). A truly socially transversal engagement practice with climate change data must consider these challenges. Furthermore, we would be engrossed in a local community, taking climate change data to a place users attend in their routine while capitalizing on the novelty of such an activity in that context. The physical installation maintained the same structure as in the pilot study, with the new iteration of the story available on the touchscreen display (Fig. 5-c). Two researchers (the first and fourth authors) were involved in the study, alternating turns during the opening house of the market. They noted observations and engaged with users to prompt them to fill out the questionnaires. The study lasted over eight days in two consecutive weeks (Wednesday to Saturday).

4.2.1. Procedure and tasks

The module was placed near the market's main entrance and worked autonomously, i.e., users could walk up to the screen and initiate the interaction. During the test, we realized that this context demanded more proactive participation from the researcher. With the installation being a new element in the market, most users did not feel at ease initiating interaction. Therefore, the researcher took a more active role in engaging the passers-by and, especially with older adult users, assisting during the interaction. This resulted in a collaborative exploration of the visualizations, becoming a bridge for dialogue between the researcher and the user.

After the initial contact, the researcher explained the nature of the activity and initiated the story. The intention was for the user to go through at least two visualizations. Afterwards, the users replied to the user questionnaire, and the ones who demonstrated more availability were further interviewed. We also asked users if they agreed to a brief follow-up interview around seven weeks later.

4.2.2. Methods

We collected data from four different sources:

1. **User questionnaire.** We conducted three demographics questions (age, gender, and education level), six questions meant to assess prior understanding of climate change matters (Table 1 questions 1 to 6), and fourteen questions adapted from the Intrinsic Motivation Inventory's (IMI) *Interest/Enjoyment* (Table 1 questions 7 to 13) and *Value/Usefulness* scales (Table 1 questions 14 to 20) (Ryan, 1982; Ryan et al., 2006). This questionnaire and particular scales were chosen for their connection with the themes being studied – interest in the information and enjoyment of its presentation; perceived usefulness of the action-focused information – and for their format that was easy and quick to answer (especially in public spaces, we needed to consider user's availability). Questions were thematically adapted to focus on the topics of the study – climate change data perception –, and were randomly ordered and answered on a scale of *1 – Strongly disagree* to *5 – Strongly agree*. This study resulted in 64 valid answers.
2. **User interview.** Afterwards, twelve users answered a semi-structured interview (I1 to I12), going deeper into the content interpretation and the user's perception of how the data was transmitted and interacted with. We asked open questions such as "What did you think of how the information was presented?"; "Do you think the information is relevant to your life in particular? Why?"; "How did the story make you feel about climate change?"; and "Did the information inspire you to take action?".
3. **Observations.** During and after the user's interaction with the installation, the researchers took notes on user comments, interaction, apparent engagement, and other relevant points. These notes were used to inform or contextualise the other results when relevant, as these observations pointed to spontaneous reactions by users.
4. **Follow-up interview.** To better understand memorability, what aspects users felt most compelled by, and possible changes in perception, we conducted a follow-up user interview of twelve open questions with eleven users (F1 to F11) six to eight weeks after the activity. Questions included: "What information most stuck in your memory?"; "Do you think the experience was different from the typical way climate change is communicated?"; "Do you think it was relevant to you personally?"; "Did your perception of climate change in any way?"; "Do you remember any of the proposals for action?";

Table 1
Results from the user questionnaire for the Main experimental study – M.E.S. ($N = 64$) and the Original Visualizations study – O.V.S. ($N = 17$). Users replied on a scale from 1 – Strongly disagree to 5 – Strongly agree.

Questions	M.E.S.	O.V.S.
1 I am familiar with the topic of climate change.	4.52	4.47
2. I am very concerned about the consequences of climate change.	4.77	4.53
3. I think my individual behavior can make a difference to climate change.	4.45	4.18
4. I think climate change is created by the media.	1.52	1.24
5. I think solving the issue of climate change is the sole responsibility of governments.	2.23	2.53
6. I am familiar with natural solutions to climate change (e.g. mangroves, forests, etc.).	3.33	3.18
7. I really enjoyed learning about whales as a natural solution to climate change.	4.88	4.41
8. Interacting with this story was fun.	4.77	3.59
9. I thought this story was very pessimistic (R).	1.91	1.70
10. Learning about whales as a natural solution to climate change did not hold my attention at all (R).	1.77	1.94
11. It was very interesting to learn about whales and climate change.	4.92	4.59
12. I found this information quite pleasing.	4.86	4.41
13. While interacting with this story, I was thinking that the information was relevant to me personally.	4.55	3.71
14. I believe this information has some value to me personally.	4.69	4.00
15. I think this activity is useful for learning about what I can do about climate change.	4.52	3.06
16. I think this information is important because it gives me a more positive perspective on climate change.	4.50	3.94
17. I would be willing to learn more about what actionsI can take on climate change because I think it has value for me.	4.75	4.59
18. I think this activity helps me to know what actions I can take regarding climate change.	4.47	2.82
19. I think doing this activity has made me more pessimistic about climate change.	2.58	2.18
20. I think this is an important topic to learn more about.	4.86	4.76

and "Did you change any behavior or did anything differently? Or are you thinking of doing things differently in the future?".

4.2.3. Participants demographics

As in the pilot study, we focused the main study on adult users (over 18 years old). The participants ($N = 81$) were diverse in age: young adults (aged 18-34): $n = 10$; adults (aged 35-64): $n = 50$; senior adults (aged 65–80+): $n = 21$. Concerning gender, $n = 28$ identified as men, $n = 52$ as women, and $n = 1$ their gender identity was not listed. The implementation context also presented an audience that was diverse in education level: primary school: $n = 9$; middle school: $n = 9$; secondary school: $n = 20$; university: $n = 43$.

4.3. Original visualizations study

Additionally, we saw it as pertinent to understand users' perceptions of the original data and its visual presentation in the IMF study (Chami et al., 2019). Therefore, we performed a parallel in-person study with seventeen users (O1 to O17), recruited from within the same community as the main study through word-of-mouth.

We asked users to reply to the same user questionnaire (4.2.2). First, there are the three demographic questions (age, gender, and education level) and the five "prior perceptions on climate change" questions. We then presented the three visualizations from the original IMF document through a touch-screen device and asked users to navigate the visualizations at will. Afterwards, we asked users to reply to the remaining questionnaire with the fourteen IMI-adapted questions. We also conducted semi-structured interviews (4.2.2) to probe further the user's perception of the data and visual presentation.

Results for the main study and original IMF visualizations study are presented in the following section.

5. Results

The answers from the user questionnaire were organised in a table, and the data was qualitatively analysed following the IMI scale (Ryan, 1982; Ryan et al., 2006). This resulted in a compilation of the average scores per question and scale. All questions and results for both the main experimental study and the original visualizations study can be found in Table 1.

The user interviews, observation notes and follow-up user interviews were transcribed and then thematically analysed (Braun and Clarke, 2022) by colour coding according to the three aspects of data humanism we focused on: a) contextualization, b) personalization and c) proposed actions. This coding led to the organisation of the qualitative data into thematic clusters that were then linked to the results of the user questionnaire to understand the impact of the tested communication dimensions. The results are presented below, first examining the users' prior knowledge and perceptions of climate change, then the overall results, and then the main analysis regarding data humanism.

5.1. Audiences' prior perceptions of climate change

The first part of the questionnaire focused on the users' prior knowledge and perceptions of climate change. These led to results (expressed as a percentage of agreement) that confirmed current trends (Leiserowitz et al., 2022). Based on the 1 to 5 Likert scale, users were very familiar with climate change – 92% (Q1), and very concerned about it – 98% (Q2). People did not believe that climate change was a media creation – 8% (Q4). Users thought their behavior could make a difference – 89% (Q3), with only 16% (Q5) thinking that the government alone should solve the issue "[the solutions] *inspired but I also think that part of this change has to be implemented by governments.*" (I8). A lower 52% (Q6) said to be familiar with natural solutions to climate change, primarily pointing to forests as the first thing that came to mind. Two users (I4, I5) expressed their surprise and unfamiliarity with the whales as carbon-capturing organisms: *"I had no idea that whales absorbed carbon."* (I4); *"I think that there should be more activities like this because I had no idea of the importance of whales."* (I5).

The follow-up interviews also point to the efficacy of engaging users with this less-known subject. All users mentioned some aspect of the whale information or marine ecosystems as the topics that first came to mind from the activity. Five users reference human impact – ocean waste, noise pollution, or vessels (F1, F2, F3, F5, F9), two mention the importance of whales in their ecosystem (F6, F8), and four mention whales as natural solutions for climate change (F4, F7, F10, F11).

The original visualizations study presented similar results for the questions related to users' general perception of and concern with climate change (Q1 to Q6). Likewise, the answers related to the importance of the information (Q17 and Q20). These results point to both groups having a similar attitude towards climate change.

5.2. Perceived enjoyment and value of the interactive installation

The overall results regarding Perceived Enjoyment and Value of the datastory installation were very positive, with participants' subjective experience related to Interest/Enjoyment at 4.61 (Q7–13) and Value/Usefulness at 4.46 (Q14–20). Not surprisingly, the original IMF visualizations scored less: with 3.48 for enjoyment and 3.62 for value. The lack of interactivity and dense visual composition of the IMF visualizations was noted by users: *"This is boring. It has a lot of text. I don't even know where to look first."* (O2). The interactive elements and story cadence of the data-story prototype helped with engagement and interpretation of the visualizations, being particularly important for communicating complex information and focusing the user's attention on certain points: "*I have trouble concentrating and changing information helps me pay attention.*" (I8); "*The interactive things, the person absorbs much more.*" (F6).

5.3. Data humanism strategy 1: contextualization of the data

5.3.1. Context through the data-story

The whale story was well received, with scores demonstrating that users immensely enjoyed learning about whales as natural solutions to climate change – 100% (Q7) and 100% (Q11). We used the whale story to give context to several data sets. For example, one of the visualizations in the prototype shows the whale population over time, becoming almost extinct but slowly recovering since 1986 (Fig. 2– first screen). Despite showing the "negative" data, we highlighted "positive" aspects to influence the data-story. Users noticed and commented on this particular point: [how they felt after the story] "*Happy to know that whales are recovering* " (P1); "*From the numbers of whales growing, I'm more optimistic*" (P11). The follow-up interviews also mentioned this positive aspect of the data-story: *"I think that little by little, as in the case of whales, it is changing because the whaling situation has drastically reduced."* (F7); *"I remember it showing some years while the number of whales increased a lot."* (F6). During the interviews, participants mentioned that since whales as nature-based solutions are not an obvious fact, the concept is more impacting and the data is easier to remember: *"I got a greater awareness of the importance that whales have in the ecosystem, and I had no idea."* (F4); *"I had no idea that whales played such an important role."* (F7); *"It was the question of the whales being ecologically a solution, which is something I was not expecting at all."* (F10).

Another impacting topic was the effect of plastic pollution in the Ocean. While this is an intensely debated issue already addressed by legislation in several countries, the story added meaning to the data by showing the consequences of plastic pollution towards the whale

characters: "*I had no idea that plastic could harm whales so much. That's what impressed me the most*" (I1); *"The reference to micro-plastics was nothing new, but it was there in a way that was perhaps more explicit and that stuck in my memory."* (F1).

5.3.2. Context through comparisons to more familiar metrics

The 100% (Q12) score also points to the information being considered as presented enjoyably. Comparing the data to more familiar contexts assisted in interpretation: "*Often when they talk about numbers, I don't know the scale, so relating to things I'm more familiar with, it's easier to understand.*" (I8); "*Having a comparison helped me to better understand the dimension of the number* " (I9). The comparisons were also mentioned in the follow-up interviews as a factor that assisted in understanding the data: "*I remember the amount of CO2 that the whales managed to accumulate inside themselves (. . .) compared to the trees.*" (F4); "*These are such huge numbers that we are unable to imagine or have a term of comparison. And I think that the visual comparisons (. . .) help a lot.*" (F11).

In the original IMF visualizations, questions for interest and enjoyment scored significantly less – 82% (Q7), 88% (Q11) and 88% (Q12). User comments point to a disconnection with the data and a lack of contextualization: *"Basically, what is the intention of this? It's just so we know: "this is good, it's already happening", or this has potential (…)?"* (O1); *"Show me comparisons. For example, compared to a car. Having a comparison with our day-to-day life."* (O8); *"I couldn't tell if it's positive or negative. The information lacks context."* (O6).

5.4. Data humanism strategy 2: personalizing the data

Results for the questions connected with the personal relevance of the data point to a lack of connection with the information presented in the original IMF visualizations – 65% (Q13) and 76% (Q14). In the interactive data-story, users thought the information was very relevant to them personally – 95% score (Q13), 98% (Q14). This suggests that the personalization strategies assisted in connection with the data.

We observed users positively engaging with the interactive elements of the story that asked them to input personal data to personalise the data-story visualizations. For example, we noted expressions of surprise when users were asked to input their height and the visualised data dynamically compared it to the whale's size ("the whale is X times your size"). These elements also granted a sense of active participation in the data-story: *"The good part is that I felt I was participating too, that this was done for us to participate and better retain the information."* (F2).

During the follow-up interviews, some users recalled the personalization elements as helpful and engaging: *"The part where you had to interact to see the countries where there were more [emissions], (. . .) I think it ends up making you curious. So when you click, you're making comparisons."* (F6); *"Since we are entering "personal" data, like age and height, we are comparing with ourselves. These comparisons helped in perceiving other numbers that are not so familiar to us on a day-to-day basis."* (F11).

5.5. Data humanism strategy 3: relating to actionable solutions

5.5.1. Positive climate change messages

Overall the data-story was not considered pessimistic – 14% (Q9) and 23% (Q19). On the other hand, when the question was formulated positively – if the information gave a more positive perspective on climate change – the results indicated agreement with an 88% score (Q16).

The user interviews echo the complexity of the issue, for example, with users commenting that the story was realistic and not necessarily pessimistic (I7). Participants voiced: "*I was a little more optimistic to know that whaling is not done as it used to be, but it also makes me worried to know that such a drastic change is needed and I don't see people doing what is necessary.*" (I8). Another user mentioned feeling "*More pessimistic because I had no idea how plastic could harm whales so much. Plastic, ships. . .* " (I1), but also that the information inspired them to take action: "*Yes. Pick up trash on the beach. Don't ignore it.* (…) *Separate the garbage at home.*" (I1). However, it is encouraging that users commented positively on the differences in the communication choices of the prototype against mainstream media: "*Usually they [the media] just say the situation is bad, but we don't know what to do.*" (I11).

The follow-up interviews validated this analysis. Nine interviewees responded that the experience did not alter their perception of climate change, with only one changing to a slightly more optimistic outlook: *"Maybe I even got a little more optimistic. Maybe it was Greta's fault, and I thought the world would end."* (F9). Another user says: *"I'm sadder because maybe I wasn't aware of the situation"*, but then they elaborate: *"But it's a good sad in the sense that I know I can also do something to change."* (F2). Nevertheless, users appreciated how the data was communicated. They considered it useful: *"I still have the same sense of alertness and responsibility, but I was left with a sense of greater awareness of the importance that whales have in the ecosystem."* (F4); *"There's a little light at the end of the tunnel also because the issue of whales, I had no idea the effect whales could have in contradicting global warming."* (F7).

5.5.2. A sense of agency by proposing action

The data-story proposals for taking action against climate change were considered helpful and created a sense of agency in climate matters. The results reveal that the activity helped teach what actions users could take, scoring 95% (Q15) and 91% (Q18). The interviews underline these results: "[if they found the information relevant] *Yes as it talks about* (…) *actions that people can do daily.*" (I6); "*There were suggestions I didn't know and are things I can do at home in the day-to-day.*" (I8). A couple of users (I2, I3) said they didn't learn much about solutions because they were already quite informed on the subject, but the experience helped to reinforce them.

In the follow-up interviews around seven weeks later, ten users (all except F2) mentioned remembering forms of action that they already implemented before the experience and, therefore, they already did what they could: *"It helped more in the perception of the problem, because in the day-to-day what I did I continue to do."* (F3); *"I already had this type of behavior, so I really didn't change anything."* (F10).

The actions listed were related to recycling ($n = 8$), plastic ($n = 6$), ocean pollution ($n = 5$), meat consumption ($n = 2$), and energy use ($n = 1$). Noticeably, several other suggestions were not mentioned. Still, the interaction with the data-story helped reinforce sustainable habits: *"I thought there are things I'm doing well and I should continue to do, and even improve."* (F1). One user said they were influenced to adopt more sustainable behaviors: *"If I see garbage, I pick it up. (. . .) I also started to do more recycling. I avoid eating so much meat."* (F2).

The two questions related to solutions presented the lowest results in the original visualizations questionnaire – 41% (Q15) and 35% (Q18). These results reflect the lack of connection to actionable proposals in the IMF visualizations. Six users explicitly commented on the lack of proposals for action: *"I have no idea what I'm supposed to do."* (O9); *"It might be helpful to specify more if there are things we can do as individuals."* (O1); *"And what can I do? Beats me! The information could link to a set of actions so people know what they can do."* (O7).

6. Discussion

In this section, we reflect on users' perceptions towards climate change datasets, and how this is shaped by the way they are communicated. We analysed the original IMF visualizations and the interactive data-story, and while we did not set up a direct comparison between the two, still understanding what did and did not work in both visualizations can point to promising techniques for engagement with climate data. In the following, we unpack insights intended to further the debate on the importance of communication choices and *how* climate change data interactions are designed. Instead of a definite generalized strategy, we aim to deepen the conversation within the design and HCI communities, fostering research that considers these aspects to better engage diverse audiences with climate change topics.

6.1. Adding context for more relatable data interactions

As Lupi mentions (G. Lupi, 2017), the data that is included or excluded defines what story is told through the visualization. By choosing additional layers of infor-mation to give context to the data, we successfully influenced the narrative the data was supporting. Also, communicating climate change through an unusual topic (whales as carbon-capturing natural solutions) effectively engaged users with the data. Furthermore, crafting the data-story around more-than-human empathy illuminates avenues of including non-anthropocentric voices in an effective way, as discussed by (Akama et al., 2020; Forlizzi, 2018). Still, we acknowledge the difficulty of representing the more-than-human (the whale and the ocean system, in our case) through human interpretation and perception. HCI work should continue to explore how to give non-human entities a voice and more prominence in our representations of climate change topics (Mencarini et al., 2023), also considering climate justice commitments (Doggett et al., 2023).

Rooting the communication activity in storytelling and mundane contexts such as the local market, brings the topic to a wider variety of audiences, including some who might not have been previously interested in topics of sustainability, a challenge discussed by (Paraschivoiu and Layer-Wagner, 2021). Equity and access, particularly in designed spaces, represent clear challenges for engagement with scientific data, with "science capital" — a concept used to assess an individual's relationship with science as a consequence of class and other socio-structural issues — representing a clear faultline (DeWitt and Archer, 2017) that HCI interventions can assist in addressing. Responding to recent calls for HCI to support science communication efforts (Williams et al., 2022), our study takes these concerns from the digital to the physical realm.

Climate change as an environmental and societal problem is now a topic that many audiences are somewhat familiar with (Leiserowitz et al., 2022). However, the scientific data and its specificities are still primarily abstract to many users. Our study demonstrated that carefully crafting the data visualizations by relating to the users' context and personal details (*humanising* the data), as called by (U. N. D. of Global Communications 2022), or creating deeper connections through a form of "participatory" data (Zhao and Sun, 2022), greatly helped in understanding the real meaning of the numbers. Information personalization strategies are well positioned to contradict the "one-size-fits-all" approach of many data visualizations (Chapman et al., 2017), and results suggest that personalization does help in connecting the user with climate change data. Our research was intended as an initial probe into applying these approaches within HCI climate change engagement. Future work should continue to explore these strategies (O'Neill et al., 2015). Engaging with different audiences within particular communities, leveraging their own experiences and stories, is a promising avenue for future design applications. Digital technologies are in a privileged position to assist in responding to this urgent engagement need.

6.2. Solutions-oriented visualizations to empower users

Most users felt the data-story helped them learn more about or reinforce what actions they could take to mitigate climate change, with proposals feeling personally relevant. Users' comments demonstrated the need for linking the data to solutions, highlighting how the story transmitted hope through action. The follow-up interviews point to the need to reinforce this solution-oriented communication and ensure that positive engagement during the activity is translated to longer-term perception. People remember best the information linking to what they already knew or did. Future research could focus on furthering personalization of the proposed actions by analysing what people already do. Also, the use of participants' mobile phones could facilitate a further and longer connection with the data. These strategies should ideally be tested through longitudinal studies.

Focusing on suggestions for action that the user can easily implement made the data feel more personal and relatable. However, despite encouraging more action-focused interactions, this result also highlights the challenge of engaging non-expert audiences with systemic change. When designing the datavisualizations and the link to actionable proposals, we considered recent criticism of SHCI regarding a generalised focus on individual action instead of broader system change (Blevis et al., 2015; Brynjarsdottir et al., 2012; Forlizzi, 2018; Knowles et al., 2018; Fritsch et al., 2019). However, the proposals for action were changed from the pilot to the main study, following user feedback (Section 4.1.3), shifting from broader social and political action to personal action. The focus of this study is not on testing possible behavior change through persuasion, an approach widely used in SHCI but that has been labelled as narrow and possibly ineffective (Brynjarsdottir et al., 2012), but rather on the importance of message creation and communication choices in climate change interactions and how they influence perception-change of such a negatively charged and biased issue. Nonetheless, our study touched on the challenge of connecting users to actions outside their personal sphere of influence, and their perceived role and responsibility within these more complex solutions. Our study connects and extends on related work pointing to potential avenues for furthering research, like engaging communities collaboratively (Aragón et al., 2021) and connecting to official institutions or environmental organizations (Paraschivoiu and Layer-Wagner, 2021). These interactions give users a sense of agency and collaborative satisfaction while linking to broader solutions. The personalization strategies discussed previously can assist in connecting particular groups to relevant action within and outside their communities.

6.3. The challenge of countering the negative framing associated with climate change

The results from the enquiry about humanized data helping users to have a more positive outlook on climate change were the most complex to evaluate. Users did not consider the data-story as pessimistic, nor that it made them more cynical about climate change. Also, they appreciated the proposals for action, as discussed in the previous section. Still, few found the experience "positive" or as giving them an optimistic outlook on the future.

The framing of how items are presented has an effect on user's adoption of sustainable behaviors, as discussed in the HCI application by (Starke et al., 2021). We build on this principle by testing it in climate change data presentation. The topic of "climate change" tends to trigger the existing negative frames already in place. For example, one user commented that when they realized it was about the impact of the Anthropocene on marine ecosystems, they expected the story to have a dramatic ending (P9). People have come to expect negative narratives associated with climate change, and even with different strategies in place to try and counter it, this hard-set bias is challenging to contradict and inevitably takes time and consistent interaction, as discussed by

(Lakoff, 2010). In response to this tendency, initiatives like Good Energy (Joyner et al., 2022) or Transmedia for Change (T4C) (Pratten, 2015) urge storytellers to engage audiences through positive messages that inspire and motivate, in line with the proposals for better climate change engagement mentioned in 2.1.1. Furthermore, the limited use of these strategies in previous HCI research (Ferreira et al., 2022) points to opportunities for using engaging interaction to communicate climate data in novel (and less neutral) forms.

Linking the audience's emotions to climate change scientific information has been explored in HCI (Aragón et al., 2021). Our research builds on this work by specifically exploring how communication strategies influence engagement with and emotional perception of the information. By carefully considering what is transmitted and how we specifically worked to advance strategies to use interactive data humanism to influence user relations with climate change topics. Our results point to the importance of not only confronting users with the topic but actively attempting to link it to personal elements or actionable proposals (Ferreira et al., 2022). Still, results also underlie the incredible complexity of communicating climate change and the difficulty of associating positive frames with this topic. The complexity of framing efficacy and alteration corroborates related work where mixed results were found in negative (Hornsey and Fielding, 2016; Ettinger et al., 2021; Bloodhart et al., 2019) versus positive messages (O'Neill and Nicholson-Cole, 2009; Feinberg et al., 2011; Hart and Feldman, 2016; Dasandi et al., 2022; Chadwick, 2015). However, recent guidelines such as (Corner et al., 2015; Chapman et al., 2016; Corner et al., 2018) call for a shift towards more positive framing focused on action. The comments made by users point to this need to present more diverse narratives that don't focus only on negative consequences.

We discussed encouraging results related to designing more relatable climate change interactions through *data humanism*, especially when focusing on action. We built upon previous research that has started to use this approach within the HCI research community, looking into applying it in the untested realm of climate change data visualisations. However, these strategies must be further tested as shifting negative bias is extremely challenging. Experimenting with novel ways of evaluating these activities and forms of assisting in the retention and application of the information opens exciting prospects for future work.

6.4. Limitations of the study

Engaging users in the evaluation process in the wild, during the time devoted to their daily routines (i.e. shopping at the local market), or allocated to specific actions (i.e. visiting a museum or a specific location) echos HCI challenges reported in research (Silva et al., 2017; Houben et al., 2019). Therefore, the testing protocols had to adapt to these particularities. Findings are limited to the degree of analysis used.

Additionally, the open nature of the design process signifies a multitude of options within each creative step. The artefact presented in this paper is but one example of application, even if applying different strategies for more accurate results. Nevertheless, research artefacts are useful even if they result from a subjective process (Hengeveld et al., 2016).

Lastly, the studies' duration was not extensive enough to determine if the experience could influence long-term perception or habit changes. This aspect was tentatively addressed in the follow-up interviews some weeks after the experience. Still, a longitudinal study would give meaningful insights into the effectiveness of the communication strategies tested.

6.5. Future directions

Besides the implications derived from the exploration of each research enquiry discussed previously, in this section we compile a set of future directions informed by the work.

Considering one of the current limitations identified, conducting long-term studies to assess further the effects of the experience on user perception and habit changes would be extremely useful. Furthermore, engaging audiences in different cultural and social contexts is a stimulating avenue for data humanism interactions moving forward, as these would explore the strategies' potential to link datasets to diverse audiences. These explorations could also consider closer links to communities and personal values – again, exploring the intrinsic potential of data humanism in connecting groups and individuals with data through their particular experiences and concerns. Additionally, alternative features within the data humanism framework and diverse datasets must be explored. As research and academic knowledge in this field evolve, it's important to update and refine the list of design insights continuously.

When looking at the results from the study and the challenges related to climate change, it is crucial to keep exploring engaging ways of connecting lay audiences with system change. The HCI community has pointed to this gap in recent years. Engaging interventions to connect complex systemic change to individual citizens and communities, making it relevant and achievable, is crucial. In addition, continuing to explore alternative ways to represent the more-than-human opens stimulating possibilities for HCI and design research. For example, the potential of Large Language Models to assist in representing different perspectives of other species is a path with great creative and conceptual potential. These explorations also demand careful debate and consideration of their limitations.

7. Conclusion

HCI and design practitioners are in a privileged position to assist in the evolution of socially responsible messages in an informative but also engaging and action-focused manner. We set out to investigate *data humanism* applied to climate change communication, focusing on storytelling, personalization, contextualization, and connection to actionable solutions. Through a research through design study, we intended to probe if and how the strategies used assisted in fostering positive and empowering interactions with climate change data. For this purpose, we conducted several studies: an evaluation of the original data visualizations from the study that informed our prototype, and two studies of our interactive data-story in two contexts – a science museum and a local food market. We used mixed methods to investigate: a) If and how users feel connected to the humanized data; b) If the humanized data affords users a positive outlook on climate change; c) If solutions-oriented visualizations create a feeling of empowerment and agency towards climate matters. Finally, we circled back to eleven participants around seven weeks later to probe memorability, what aspects users felt most compelled by, and possible changes in perception.

The data humanism approach challenges a sector of data visualization that focuses on neutrality and simplicity for effective data communication (Zhao and Sun, 2022; Tufte, 2013; Cairo, 2016) leaning towards an observer-dependant, more complex and nuanced approach (Drucker, 2011) in an attempt of reconnecting audiences with climate change data. Our results suggest that adding layers of information to contextualize the data helps engage and connect with climate change data and that solutions-oriented visualizations effectively engage users and create or reinforce a feeling of agency in climate matters. However, even though users appreciate the focus on action, the tested interactions with humanized data were insufficient to alter the person's perception of the issue considerably.

In summary, the insights and discussion generated from the study illuminate the potential of combining data humanism with HCI interventions. This paper intends to deepen the debate surrounding the complexity of engaging diverse audiences with climate change data and building on the challenges of shifting the climate change dialogue from one focused on "doom and gloom" to action-focused narratives. In this context, designing data visualizations that are relatable and focused on solutions might be as important as accuracy. These inquiries underlie the

ever-growing role that interactive experiences can and should play in these crucial communication challenges.

CRediT authorship contribution statement

Marta Ferreira: Writing – original draft. **Nuno Nunes:** Writing – review & editing. **Pedro Ferreira:** Data curation. **Henrique Pereira:** Data curation. **Valentina Nisi:** Writing – review & editing.

Declaration of competing interest

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Data availability

The data that has been used is confidential.

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