Climatic Change (2024) 177:81
https://doi.org/10.1007/s10584-024-03725-2

Public understanding of climate change terminology in Germany

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Received: 15 June 2023 / Accepted: 24 March 2024 / Published online: 15 May 2024

Abstract

The United Nations' Intergovernmental Panel on Climate Change (IPCC) and other institutions communicate about climate change to international audiences without a background in climate science, including the general public. The effectiveness of climate change communications may be undermined by their use of complex terminology. Bruine de Bruin et al. (2021) found that Americans struggled to understand key terms from IPCC reports. Here, we examined how 24 Germans interpreted German translations of these key terms, including tipping point, unprecedented transition, carbon neutral, carbon dioxide removal from the atmosphere, adaptation, mitigation of climate change/ of greenhouse gas emissions, sustainable development, and abrupt change. We also presented these terms in the context of sentences taken from German-language IPCC reports. We identified common themes and misunderstandings. Overall, 93% of the themes arose by the 10th interview, and no new themes arose after the 18th interview. While interviewees initially rated most terms as easy to understand, both climate-concerned and climate-ambivalent interviewees were unfamiliar with some terms or combinations of terms, unsure of the link to climate change, and confused about details. Some also expressed mistrust. Moreover, all sentences were perceived as too long and complex. We discuss the implications of these findings for climate change communications.

Keywords Climate communication · Expert terminology · Language

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1 Introduction

Tackling climate change requires action from big businesses, policy makers, and members of the public (UNESCO 2021). To inform people's decisions about climate change, organizations such as the United Nation Intergovernmental Panel on Climate Change (IPCC) regularly summarize the latest scientific climate evidence in publicly available reports. IPCC reports, including so-called 'summaries for policy makers', have become frequently read and quoted in the media. IPCC findings are also shared by policy makers when addressing public audiences (Brüggemann et al. 2018), and summarized in 'derivative' communications for special audiences such as teachers.

The effectiveness of climate change communications may depend in part on how well the presented terminology is understood. The science of science communication posits that text is more understandable if presented words have no more than two syllables, and presented sentences have 16–20 words (Cutts 2013; Kadayat and Eika 2020; McLaughlin 1969). Unfortunately, much longer words and sentences tend to be used in climate change reports from the IPCC and other organizations like the UK Met Office (Barkemeyer et al. 2016; Kause et al. 2020). While IPCC reports are written at university-level (Barkemeyer et al. 2016), the average reading comprehension skills of adults in countries like Germany, US and UK are at the level of educated 12–13-year-olds (Daraz et al. 2011; Davis et al. 2006; Neuhauser and Paul 2011; OECD 2013; Paasche-Orlow et al. 2003). Moreover, climate change communications may include jargon such as 'adaptation' and 'mitigation' that people find confusing (Harcourt et al. 2019).

Theories of how people make sense of new information suggest that they may draw on their understanding of other contexts – or mental models (Bruine de Bruin and Bostrom 2013; Reynolds et al. 2010). A recent study by Bruine de Bruin et al. (2021) found that people try to interpret complex climate change terms on the basis of their existing knowledge of what terms mean in other contexts. Specifically, Bruine de Bruin et al. (2021) presented 20 US residents with diverse views on climate change with terms that were selected by IPCC authors because of their central importance to climate change communications. Those terms included tipping point, unprecedented transition, carbon neutral, carbon dioxide removal, adaptation, mitigation, sustainable development, and abrupt change. Climate-concerned and climate-ambivalent interviewees raised similar issues when trying to interpret these terms. Reading the terms in the context of sentences from IPCC reports was not always helpful due to sentences' complexity. Based on interviewees' interpretations and the science communication literature, Bruine de Bruin et al. (2021) recommended simplifying wording, making links to climate change explicit, and describing relevant details.

One limitation of Bruine de Bruin et al.'s (2021) study is that it focused on the United States. For three reasons, Germans may be more familiar with complex climate change terms than Americans. First, having greater climate change concerns has been associated with better climate change understanding (Shi et al. 2016). Indeed, Germans are more concerned about climate change than Americans: 91% of Germans and 74% of Americans reported being "somewhat" or "very" concerned about climate change in the Lloyd's Register Foundation World Risk Poll (Lloyd's Register Foundation 2021). Second, levels of climate skepticism are low in Germany, and people with lower levels of climate skepticism may be used to scientific terms over polarizing language. Third, while Germans and Americans are on average similarly literate (OECD 2013), Germans may be more used

to complex wording because the German language is inherently more complex than the English language (Günther et al. 2019).

Following Bruine de Bruin et al. (2021) we therefore address understanding of climate change terms used in German IPCC outlets among German interviewees through the following research questions:

1. How do German interviewees rate the understandability of key terms and sentences?
2. How do German interviewees interpret the terms and sentences?
3. Which recommendations do German interviewees make for improving terms and sentences?

2 Methods

2.1 Sample

We recruited 24 German residents for interviews about "climate change communications." Twenty were reached through Prolific's online platform and four through science-sceptical online platforms. Mean age was 38 (SD = 13.6). Twelve (50%) identified as female and twelve (50%) as male. Six (25%) had completed secondary school, and eighteen (75%) had a university degree (Supplementary Information A).

The sample size was sufficient: The "saturation point", meaning the point at which all themes were identified (Hennink et al. 2017) varied from the fifth interview (for 'carbon dioxide removal from the atmosphere' and 'abrupt change') to the 18th interview (for 'tipping point'). Overall, 93% of identified codes emerged within the first ten interviews.

We identified eighteen (75%) interviewees as "climate-concerned". They indicated that climate change was "caused mostly by human activities". Six (25%) did not agree with this interpretation, and are henceforth referred to as "climate-ambivalent" (Bruine de Bruin et al. 2021).

2.2 Procedure

Our recruitment survey (Supplementary Information B) assessed climate views, using German translations of multiple-choice questions from Bruine de Bruin et al. (2021): "Climate change is …(a) caused mostly by human activities; (b) caused by natural changes in the environment; (c) isn't happening; (d) none of these". It also asked about the likelihood that climate change is currently happening on a scale ranging from 1 (= very unlikely) to 5 (= very likely). Interviewees received €0.60 for completing the recruitment survey. Interviews were conducted via phone or Zoom in September–November 2022, following a German version of Bruine de Bruin et al.'s (2021) interview protocol (Supplementary Information C). Interviewees clicked on a link to see, in order, the terms 'mitigation of climate change/ of greenhouse gas emissions' (*Minderung des Klimawandels / von Treibhausgasemissionen),* 'carbon neutral' *(CO_2-neutral),* 'unprecedented change' (*Beispiellose Veränderung),* 'tipping point' *(Kipppunkt),* 'sustainable development' *(Nachhaltige Entwicklung),* 'carbon dioxide removal from the atmosphere' *(Kohlenstoffdioxidentnahme aus der Atmosphäre),* 'adaptation' *(Anpassung)*, and 'abrupt change' (*Abrupte Veränderung;* Table 1). German translations of key terms originated from IPCC websites (https://www.de-ipcc.de/

Table 1 Ratings of presented terms and sentences

Term	Sentence	Mean (SD) rating			*N* (%) unfamiliar with (combination of) terms
		Term	Sentence	Comparison of ratings of term and sentence, as indicated by paired-sample *t*-tests	
Carbon dioxide removal from the atmosphere (*Kohlenstoffdioxidentnahme aus der Atmosphäre*)	Modeled mitigation strategies to achieve these reductions include transitioning from fossil fuels without CCS to very low-carbon or zero-carbon energy sources, such as renewables or fossil fuels with CCS, demand-side measures, and efficiency improvements, reduction of non-CO_2 emissions, and the use of carbon dioxide removal (CDR) techniques to balance remaining GHG emissions *Die modellierten Minderungsstrategien zur Erreichung dieser Senkungen umfassen den Übergang von fossilen Brennstoffen ohne CCS zu sehr kohlenstoffarmen oder kohlenstofffreien Energiequellen, wie erneuerbaren Energien oder fossilen Brennstoffen mit CCS, nachfrageseitige Maßnahmen und Effizienzsteigerungen, die Senkung von Nicht-CO_2-Emissionen sowie den Einsatz von Methoden zur Kohlendioxid-Entnahme (Carbon Dioxide Removal, CDR), um verbleibende Treibhausgasemissionen auszugleichen*	3.48^{ms} (1.33) $t(23) = 1.76$, $p = .05$	1.56^{m} (0.77) $t(23) = -9.14$ $p < .001$	$t(23) = 5.64$, $p < .001$	11 (46%)

Table 1 (continued)

Term	Sentence	Mean (SD) rating			*N* (%) unfamiliar with (combination of) terms
		Term	Sentence	Comparison of ratings of term and sentence, as indicated by paired-sample *t*-tests	
Carbon neutral (*CO_2-neutral*)	Achieving global net zero CO_2 emissions, with anthropogenic CO_2 emissions offset by anthropogenic removals of CO_2, is a prerequisite for stabilizing the CO_2-induced increase in global surface temperature *Das Erreichen von globalen netto null CO_2-Emissionen, wobei anthropogene CO_2-Emissionen durch anthropogene Entnahmen von CO_2 ausgeglichen werden, ist eine Voraussetzung für die Stabilisierung des CO_2-bedingten Anstiegs der globalen Oberflächentemperatur*	3.54^{ms} (1.28) $t(23) = 2.07$, $p = .03$	1.94^{m} (0.86) $t(23) = -6.03$, $p < .001$	$t(23) = 6.33$, $p < .001$	0 (0%)
Tipping point (*Kipppunkt*)	Abrupt reactions and tipping points of the climate system, such as a sharp increase in the melting of the Antarctic ice sheet or forest dieback, cannot be ruled out *Abrupte Reaktionen und Kipp-Punkte des Klimasystems, wie z.B. eine starke Zunahme beim Abschmelzen des Antarktischen Eisschilds oder Waldsterben, können nicht ausgeschlossen werden*	3.79^{m} (0.83) $t(23) = 4.66$, $p < .001$	3.73^{m} (0.87) $t(23) = 4.10$, $p < .001$	$t(23) = 0.41$, $p = .35$	13 (54%)

Table 1 (continued)

Term	Sentence	Mean (SD) rating			*N* (%) unfamiliar with (combination of) terms
		Term	Sentence	Comparison of ratings of term and sentence, as indicated by paired-sample *t*-tests	
Unprecedented transition (*Beispiellose Veränderung*)	The magnitude of the most recent changes in the overall climate system—and the current state of many aspects of the climate system – have been unprecedented for many centuries to millennia *Das Ausmaß der jüngsten Veränderungen im gesamten Klimasystem – und der gegenwärtige Zustand vieler Aspekte des Klimasystems – sind seit vielen Jahrhunderten bis Jahrtausenden beispiellos*	3.88^{m} (1.15) t(23) = 3.72, $p < .001$	3.60^{m} (1.09) t(23) = 2.71, $p = .006$	t(23) = 1.21, $p = .12$	11 (46%)
Mitigation of climate change/ of greenhouse gas emissions (*Minderung des Klimawandels / von Treibhausgas-Emissionen*)	Accelerated and fair measures to mitigate and adapt to the impacts of climate change is critical for sustainable development *Beschleunigte und gerechte Maßnahmen zur Minderung der, und Anpassung an, die Folgen des Klimawandels sind für eine nachhaltige Entwicklung entscheidend*	4.04^{ms} (1.01) t(23) = 5.05, $p < .001$	2.44^{m} (1.17) t(23) = −2.35, $p = .01$	t(23) = 7.70, $p < .001$	11 (46%)

Table 1 (continued)

Term	Sentence	Mean (SD) rating			*N* (%) unfamiliar with (combination of) terms
		Term	Sentence	Comparison of ratings of term and sentence, as indicated by paired-sample *t*-tests	
Sustainable Development (*Nachhaltige Entwicklung*)	The Sustainable Development Goals (SDGs), adopted as part of the UN 2030 Agenda for Sustainable Development, can serve as a basis for evaluating climate action in the context of sustainable development *Die Ziele für nachhaltige Entwicklung (Sustainable Development Goals, SDG), die im Rahmen der UN-Agenda 2030 für nachhaltige Entwicklung verabschiedet wurden, können als Grundlage für die Bewertung von Klimaschutzmaßnahmen im Kontext der nachhaltigen Entwicklung dienen*	4.15^{ms} (0.90) $t(23) = 6.22$, $p < .001$	2.85 (1.05) $t(23) = -0.68$ $p = .25$	$t(23) = 6.63$, $p < .001$	1 (4%)

Table 1 (continued)

Term	Sentence	Mean (SD) rating			*N* (%) unfamiliar with (combination of) terms
		Term	Sentence	Comparison of ratings of term and sentence, as indicated by paired-sample *t*-tests	
Abrupt change (*Abrupte Veränderung*)	Impacts with low probability of occurrence—such as collapse of ice sheets, abrupt changes in ocean circulation, some compound extreme events, and warming well beyond the range of future warming assessed as very likely—cannot be ruled out and are part of the risk assessment *Effekte mit geringer Eintrittswahrscheinlichkeit – wie der Zusammenbruch von Eisschilden, abrupte Veränderungen der Ozeanzirkulation, einige zusammengesetzte Extremereignisse und eine Erwärmung, die wesentlich über die als sehr wahrscheinlich bewertete Bandbreite der künftigen Erwärmung hinausgeht – können nicht ausgeschlossen werden und sind Teil der Risikobewertung*	4.33^{ms} (0.67) $t(23) = 9.75$, $p < .001$	3.33^{m} (0.78) $t(23) = 2.11$, $p = 0.02$	$t(23) = 6.93$, $p < .001$	3 (13%)

Table 1 (continued)

Term	Sentence	Mean (SD) rating			*N* (%) unfamiliar with (combination of) terms
		Term	Sentence	Comparison of ratings of term and sentence, as indicated by paired-sample *t*-tests	
Adaptation (*Anpassung*)	Accelerated and fair measures to mitigate and adapt to the impacts of climate change is critical for sustainable development *Beschleunigte und gerechte Maßnahmen zur Minderung der, und Anpassung an, die Folgen des Klimawandels sind für eine nachhaltige Entwicklung entscheidend*	4.75[ms] (0.68) t(23) = 12.69, $p < .001$	3.56[m] (0.92) t(23) = 2.98, $p < .01$	t(23) = 5.54, $p < .001$	0 (0%)

[m]Significantly different from scale midpoint of 3, in a one-sample *t*-test ($p < 0.05$)

[s]Significantly higher than rating for sentence, in a paired-sample *t*-test ($p < 0.05$). Because we could not identify a German sentence including the entire term 'CO_2 neutral' participants were presented with one including parts of the term. Supplementary Information D provides sentence sources

media/content/Begriffe_IPCC_online.pdf). These translations and their importance for German-language communications were confirmed by a German IPCC Working Group II communications team member. Sentences were taken from German summaries for policy makers of the IPCC's Sixth Assessment Report (Supplementary Information D). One sentence was presented twice, for two different terms (Table 1). We calculated Flesch-Kincaid scores, which reflect US grade levels required to understand text (Flesch 1948). Those ranged from 16 to 30 (Supplementary Information E), reflecting university-level language. This is in line with readability metrics identified for previous English-language IPCC summaries for policy makers (Barkemeyer et al. 2016).

Each term first appeared on its own. Interviewees read it out loud, indicated whether they had heard it before, and gave their interpretation. They rated how easy it was to understand on a scale from 1 (= not understandable at all) to 5 (= very easy to understand). Interviewees then read the associated sentence, interpreted it, and rated its ease of understanding on a scale from 1 (= not understandable at all) to 5 (= very easy to understand). They were also asked to suggest alternative wording. At the end of the interview, the two questions from the recruitment survey were repeated. Interviewees then received 20€. The study was approved in June 2022 by the Ethics committee of Leuphana University of Lüneburg (Votum_EB_Antrag_202205-09_Kause_Klimaterminologie).

2.3 Coding

All interviews were recorded and transcribed word for word (see https://osf.io/g8kh9/ for original German transcripts). The first author identified common themes in each interview (Braun and Clarke 2006), with guidance from the other authors. A randomly selected subset of 4 interviews was presented to an independent second coder. After discussion of initial disagreements, Cohen's Kappa, which reflects inter-rater agreement after correcting for chance, was sufficient at 0.87, with an 80% overlap of codes.

3 Results

3.1 How did interviewees rate the terms and sentences?

Table 1 shows that interviewees rated all terms and all but one sentence as relatively easy to understand. The terms were rated as easier to understand than the sentences. Only 'tipping point' and 'unprecedented transition' showed no significant difference between mean ratings for term and sentence (Table 1).

3.2 How did interviewees interpret the terms and sentences?

For each term, we flagged whether interviewees were unfamiliar with the term or combination of terms, found the link to climate change unclear, or were unsure about details (Tables 2 and 3). We also indicated whether interviewees expressed mistrust about the term or its associated sentence (Table 2). For each sentence, we indicated whether interviewees found it ambiguous or struggled with the length (Table 2). We report how many interviewees raised each issue, with the caveat that qualitative interviews are designed to identify *which issues arise, and not how often they arise* (Bruine de Bruin and Bostrom 2013). Where possible, we present quotes about every issue from climate-concerned and from

Table 2 Issues raised about each term and sentence

	Unfamiliar (combination of) terms	Term's link to climate change unclear	Term's details unclear	Mistrust towards term or sentence	Sentence is ambiguous	Sentence too long
Carbon dioxide removal from the atmosphere	X	X	X		X	X
Carbon neutral		X	X	X		X
Tipping point	X	X	X		X	X
Unprecedented transition	X	X	X	X	X	X
Mitigation of climate change/ of greenhouse gas emissions	X	N/A	X		X	X
Sustainable development		X	X		X	X
Abrupt change	X	X	X		X	X
Adaptation		X	X		X	X

The 'X' denotes that issues in this table were raised by at least two interviewees; blank spaces denote that issues were raised once or not at all. 'N/A' denotes Non-Applicable, because climate change was mentioned alongside "mitigation"

Table 3 IPCC definitions of presented terms

Term	Definition from IPCC SR15 glossary, unless otherwise noted
Carbon dioxide removal from the atmosphere	Human activities to remove carbon dioxide (CO_2) from the atmosphere and durably store it in geological, terrestrial, or ocean reservoirs, or in products. It includes existing and potential human enhancement of biological or geochemical sinks and direct air capture and storage, but excludes natural CO_2 uptake not directly caused by human activities
Carbon neutral	Carbon neutrality is achieved when anthropogenic CO_2 emissions are balanced globally by anthropogenic CO_2 removals over a specified period. Carbon neutrality is also referred to as net-zero CO_2 emission
Tipping point	A level of change in system properties beyond which a system reorganizes, often abruptly, and does not return to the initial state even if the drivers of the change are abated. For the climate system, it refers to a critical threshold when global or regional climate changes from one stable state to another stable state
Unprecedented transition	Transition: the process of changing from one state or condition to another in a given period of time. Transition can be in individuals, firms, cities, regions, and nations and can be based on incremental or transformative change. (No definition for "unprecedented" transition available.)
Mitigation of climate change/ of greenhouse gas emissions	Mitigation (of climate change): a human intervention to reduce emissions or enhance the sinks of greenhouse gases
Sustainable development	Development that meets the needs of the present without compromising the ability of future generations to meet their own needs and balances social, economic, and environmental concerns
Abrupt change	An "abrupt change" is defined as a regional to global scale event that occurs much faster than the rate of climate change that caused the event (source: SROCC)
Adaptation	In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate and its effects

The IPCC SR15 glossary used here as well as in the original study by Bruine de Bruin et al. (2021) can be accessed at: https://www.ipcc.ch/sr15/chapter/glossary/. Glossaries of AR6 Working Groups differed only slightly (https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_Annex-II.pdf). German translations of the terms can be accessed at: https://www.de-ipcc.de/media/content/Begriffe_IPCC_online.pdf

Here, we provide only English definitions of the key terms since we could not find official German translations of definitions

climate-ambivalent interviewees (as defined in the Methods). We present English translations of quotes (see Supplementary Information F for German originals). We also provide recommendations for making communications easier to understand.

3.2.1 Carbon dioxide removal from the atmosphere

Potential confusion This term was rated as the most difficult (Table 1). Eleven interviewees (46%) were unfamiliar with the term or combination of terms. One said she heard it in "biology class, when we discussed photosynthesis, but not in a climate-context" (interview 2, climate-concerned). Another added "[I] can't imagine what that means" (interview 20, climate-ambivalent). For seven interviewees (29%), the link to climate change was unclear: "Perhaps it means more restrictions on air traffic? They want people to fly less" (interview 15, climate-concerned). Another said "plants do it, but I don't know in which context carbon dioxide removal works" (interview 20, climate-ambivalent). Fifteen (63%) were unsure about the details. For example, an interviewee stated: "I understand what it means but I can't describe any concrete measures for removing CO_2 from the atmosphere." (interview 10, climate-concerned). Another said: "How does this work and how can it be achieved? Are there filters? What is the process?" (interview 17, climate-ambivalent). Fifteen interviewees (63%) mentioned forests or plants for binding carbon dioxide, such as: "I know that plants do it. They absorb carbon dioxide. But I don't know how this works in an environmental context" (interview 8, climate-concerned). Another said: "What I would like it to mean is reforestation of rainforests. Because let's leave the carbon dioxide removal from the atmosphere to the trees. All plants need carbon dioxide, after all" (interview 24, climate-ambivalent). None described other means for carbon dioxide removal from the atmosphere. Four climate-concerned interviewees (17%) thought that carbon dioxide could be re-purposed, with one stating: "CO_2 could be transformed into renewables or other energy using CCS, this could be a neutral way to produce electricity or fuels" (interview 7, climate-ambivalent). None expressed mistrust towards the term or sentence.

Additionally, five (21%) described the sentence as ambiguous, for example: "I didn't get the sentence, I have to admit" (interview 15, climate-concerned). Another was confused about the meaning of the sentence: "How should I interpret this part of the sentence [about capturing carbon dioxide]?" (interview 24, climate-ambivalent). Twenty (83%) struggled with jargon like "CCS". Eighteen (75%) mentioned the nested sentence or length, noting that "it's extremely long with many subclauses" (interview 13, climate-concerned) and an "endless nested sentence" (interview 21, climate-ambivalent).

Recommendations Interviewees recommended simpler wording. Instead of "carbon dioxide," they suggested saying "greenhouse gases" (interview 7, climate-concerned) or "CO_2" (interview 20, climate-ambivalent). Another preferred "binding" over "removal" (interview 14, climate-concerned). It was also suggested to explain what CCS means, "including a German translation" (interview 5, climate-concerned).

To clarify details, interviewees recommended explaining how carbon dioxide is removed from the atmosphere, such as "sucking carbon from the air with filters" (interview 14, climate-concerned) and "fertilizing the ocean floor to feed micro organisms to help with more productive photosynthesis" (interview 21, climate-ambivalent). Interviewees also suggested mentioning the binding of carbon in solid form and storing it in underground reservoirs (interviews 9 and 10, climate-concerned; interview 21 and 24, climate-ambivalent). Interviewees also proposed splitting up the sentence into several shorter ones (interview 16, climate-concerned; interview 24, climate-ambivalent).

3.2.2 Carbon neutral

Potential confusion This term was rated as the second-most difficult (Table 1). Nevertheless, all interviewees indicated being familiar with the term: "especially in the last 2–3 years, this became a common term" (interview 1, climate-concerned). For two interviewees (8%), the link to climate change was unclear, with an interviewee saying: "It might mean less greenhouse gas emissions, [but] I really can't explain exactly what [carbon neutral] means" (interview 23, climate-concerned). Another one asked: "I heard this is somehow connected to renewable energies, right?" (interview 20, climate-ambivalent). Seven interviewees (29%) were unsure about the details. For example, they admitted "Because it is used so often, it is relatively clear what it means, but perhaps not in detail" (interview 14, climate-concerned) and "it might mean less greenhouse gas emissions, [but] I really can't explain exactly what [carbon neutral] means" (interview 23, climate-concerned). One interviewee also asked: "I think electric cars are sold as carbon neutral? What else is carbon neutral?" (interview 20, climate-ambivalent). Thirteen (54%) did mention details. For example, one interviewee explained it as "[the way] a product [is] manufactured, packaged and distributed, with no additional CO_2 emitted into the atmosphere" (interview 6, climate-concerned). Others remained general: "Large companies' advertisements use the term CO_2 neutral to describe the products they sell" (interview 24, climate-ambivalent). Eight (33%) confused the term with zero emissions and compensation. For example, one said "during [products'] life cycle, no additional CO_2 is emitted into the atmosphere" (interview 4, climate-concerned). Another suggested "I think something happens where no carbon dioxide is emitted" (interview 24, climate-ambivalent). Six interviewees (25%) expressed mistrust, perceiving "carbon neutral" as deceptive: "If you ask what is behind it, how do you come to CO_2 neutrality then you realize that it's in fact a lie" (interview 6, climate-concerned). Another described the term as "greenwashing" because "you can have an oil heating system and plant a forest somewhere for it. And suddenly, the oil heating is carbon neutral" (interview 18, climate-ambivalent).

Only one interviewee described the sentence as ambiguous and said "this is vague." (interview 22, climate-concerned). Fourteen (58%) mentioned the nested sentence or length. One complained: "This is horribly cumbersome. Many, too many subclauses" (interview 10, climate-concerned). Another mentioned having to read it more than once: "You see? Now I thought, that's not true, because I forgot again how the sentence started" (interview 24, climate-ambivalent). Eighteen (75%) also suggested avoiding jargon. For example, an interviewee noted "It's very long and uses something … anthropogenic, I'm not familiar with this term. I think many people won't know it either and will be overwhelmed by the long sentence" (interview 7, climate-concerned). Another interviewee requested clarification: "I think you almost must go to university for that. I don't know, what are anthropogenic CO_2 emissions, really? Are cow farts part of them? Do they include a campfire? I don't know" (interview 18, climate-ambivalent).

Recommendations Fourteen (58%) preferred using simpler wording such as "balanced" (interview 1, climate-concerned), or "evened" (interview 9, climate-concerned; interview 19, climate-ambivalent). Other suggestions were to replace CO_2 with carbon dioxide (interview 19, climate-concerned) and to mention other greenhouse gases (interview 21, climate-ambivalent). Communications should explicitly link the term to climate change and provide relevant details, including why and how carbon neutrality must be achieved (interview 14, climate-concerned), and how carbon neutrality is different from zero emissions (interview

3, climate-concerned). Examples of technical strategies may be needed to make it clear that carbon neutrality entails more than planting forests (interview 18, climate-ambivalent). We also suggest using short sentences that include examples, such as "the emissions were compensated by …[name a measure for carbon dioxide removal]", e.g. reforestation (interviews 18 and 24, climate-ambivalent).

3.2.3 Tipping point

Potential confusion This term was ranked as the third-most difficult (Table 1). Thirteen (54%) were unfamiliar with the term, or combination of terms. For example, interviewees stated "I may have read it somewhere, but I'm not sure" (interview 5, climate-concerned) and "I've never heard it before" (interview 20, climate-ambivalent). For nine interviewees (38%), the link to climate change was unclear. For example, one said "the way I understand it, something in a system, whatever the context, changes so much that some kind of chain reaction is triggered" (interview 10, climate-concerned). Another interviewee confessed: "I don't know this term's context. I'd assume this means negative change?" (interview 20, climate-ambivalent). Fifteen interviewees (63%) recognized that crossing a tipping point makes reverting to a previous state impossible. An interviewee mentioned: "I imagine tipping point means, there is no turning back" (interview 3, climate-concerned). Another said: "This culmination towards a certain point, at which possibly, but possibly not, irreversible changes occur" (interview 21, climate-concerned). Merely two interviewees (8%) said "climate changes from one stable state to another stable state" (interviews 4 and 11, climate-concerned), thus capturing a central part of the term's definition (Table 3). Nine interviewees (38%) were unsure about the details. They expressed confusion about whether the term referred to human actions or to climate change. For example, an interviewee said: "[The term] is not defined that precisely. Do they mean the tipping point when we have to change something or tipping point when the climate changes?" (interview 15, climate-concerned). Another interviewee asked "tipping point—is that something like a turning point, in a negative sense"? (interview 20, climate-ambivalent). Six interviewees (25%) described tipping points as turning points or said in English "point of no return". Ten interviewees (42%) thought the term was a metaphor, but their interpretations hardly covered the definition (Table 3). For example, one interviewee suggested: "a car tips over the precipice [or] filling something until it tips over, or a lake [that] tips over" (interview 6, climate-concerned). Others mentioned "dump[ing] something, then it's no longer retrievable either" (interview 9, climate-concerned), "boil[ing] water at 100 degrees, [then] it boils over" (interview 18, climate-ambivalent), "the moment when the sand from the excavator shovel tips onto the loading area " (interview 17, climate-ambivalent), and "driving up a mountain and then somewhere it doesn't go any higher, but then it goes down again" (interview 24, climate-ambivalent). One interviewee connected the term to rising sea levels: "overflowing sea level, and then at some point it just overflows somewhere and then some basin is gone, then this overflow point would also be somehow such a tipping point" (interview 18, climate-ambivalent). None expressed mistrust towards the term or sentence.

Two climate-ambivalent interviewees (8%) described the sentence as ambiguous. For example, one stated "Does this suggest that this is possible or that it may happen? Or is it to be expected that it will happen? It is not quite clear to me what is expressed here" (interview 20, climate-ambivalent). Four interviewees (16%) complained about the nested sentence or length. For example, one mentioned: "Some parts are … it's relatively, if you read it two to three times, relatively easy to understand what this is about" (interview 15,

climate-concerned). Another stated that "it is not simple enough for everyday people, I think" (interview 24, climate-ambivalent).

Recommendations Interviewees suggested using familiar words. Six climate-concerned interviewees (25%) mentioned the English phrase: "point of no return." Six (25%), including two who were climate-ambivalent (interview 17 and 20), suggested, in English: "turning point". Interviewees also suggested alternative terms such as "abrupt reaction" (interview 5, climate-concerned), "negative change" (interview 20, climate-ambivalent), or "drastic consequences" (interview 23, climate-concerned). To clarify the link to climate change, one recommended describing tipping points in a climate context (interview 15, climate-concerned). This needs to highlight that climate changes from one stable state to another less predictable state with more severe, "worse" consequences (interview 11, climate-concerned). Descriptions could include "abrupt reaction" (interview 5, climate-concerned), "negative change" (interview 20, climate-ambivalent), or "drastic consequences" (interview 23, climate-concerned) and more details, such as the melting of (Arctic and Antarctic) ice sheets (interview 22, climate-concerned; interview 21, climate-ambivalent) or a dieback of the Amazonian rain forest (interview 22, climate-concerned). One interviewee also suggested splitting up the sentence into several shorter ones (interview 9, climate-concerned).

3.2.4 Unprecedented transition

Potential confusion This term was ranked as the fourth-most difficult (Table 1). Eleven interviewees (46%) were unfamiliar with the term, or combination of terms. For example, one interviewee said that the terms were familiar, but "not in this combination" (interview 6, climate-concerned). Another interviewee added: "Not [familiar] indeed. Maybe because I limit my media exposure" (interview 21, climate-ambivalent). For seventeen interviewees (71%), the link to climate change was unclear, with an interviewee saying: "If you say that someone else has made an unprecedented change to their personality and is an entirely different person now. I haven't heard this in other contexts" (interview 2, climate concerned). Another interviewee said: "So literally that means, I'm going to change something, but I don't have a model for it, I'll just try something" (interview 24, climate-ambivalent). Three interviewees (13%) recognized that the term is widely used, but had varying definitions. The term "unprecedented" was misinterpreted to mean "inefficient" (interview 13, climate-concerned), "without alternative" (interviews 5 and 6, climate-concerned), or "exemplary" (interview 23, climate-ambivalent). Eight (33%) were unsure about the details. For example, one interviewee said: "Climate change comes with unprecedented change, without specifying what this change is about. That doesn't tell me anything" (interview 9, climate-concerned), and another one: "Unprecedented, what does that mean?" (interview 17, climate-ambivalent). Two (8%) expressed mistrust, because they perceived the term as populist. For example, an interviewee called it "political jargon […] It's a super clickbait headline" while adding: "[How meaningful] are centuries, when we, when the earth is millions of years old? [How meaningful] are millennia when the Romans cultivated wine in England 2000 years ago? So that's what I would say immediately in response to a sentence like that" (interview 22, climate-concerned). Another agreed that the term reflected "politicians' language. This is very pompous I'd say" (interview 17, climate-ambivalent). Six interviewees (25%) doubted whether climate change was unprecedented. For example, one said: "This change is not unprecedented. Climate has already changed in all possible directions on earth several times, which means that there are at least rough

examples, even if no one was there" (interview 9, climate-concerned). Another agreed: "It is not even true. There has already been climate change. When the dinosaurs went extinct or the ice age or something. But well, that was maybe thousands of years ago" (interview 18, climate-ambivalent). Only one explicitly mentioned that current climatic changes happen much faster than before, due to industrialization (IPCC 2021): "Climate change is not unprecedented. But how we push forward industrialization is unprecedented" (interview 19, climate-concerned).

Six interviewees (25%) described the sentence as ambiguous, partly because they were unsure about how to interpret "unprecedented". For example, one interviewee noted: "there are two possibilities for interpreting the term 'unprecedented' in this sentence" (interview 5, climate-concerned). Another said: "Of course, again, you can interpret this sentence in any way you want. I would have preferred to know more precisely what is meant … have we had climate change for millennia? And is it unprecedented compared to millions of years? That's how I first interpreted the sentence. But this should be compared to centuries to millennia" (interview 24, climate-ambivalent). Eight (33%) mentioned the nested sentence or length (33%). For example, they noted "I needed to read it two or three times. This is complicated, the grammar is very complicated" (interview 9, climate-concerned) and "well, someone who thinks in a simple way will stop reading or listening after a few words." (interview 24, climate ambivalent).

Recommendations Interviewees suggested simpler wording such as "unique" (interview 5, climate-concerned), "dramatic" (interview 18, climate-ambivalent), "something that never happened before" (interview 23, climate-concerned) and "paradigm change" (interview 21, climate-ambivalent). The term needs to be presented with a clear link to climate change and with relevant details, including examples referring to the expansion of the renewable energy sector (interview 15, climate-concerned) or concerted action as human species (interview 21, climate-ambivalent). To address mistrust, it may be helpful to explain that climate change has always existed (interview 4, climate-concerned), but that it is presently more drastic (IPCC 2023) and therefore requires unprecedented societal transitions. Interviewees also suggested splitting the sentence into several shorter ones (interviews 7 and 9, climate-concerned).

3.2.5 Mitigation of climate change/ of greenhouse gas emissions

Potential confusion This term was ranked as the fifth-most difficult (Table 1). Eleven interviewees (46%) were unfamiliar with the term or combination of terms. For example, one said knowing about "mitigation – yes, but not in a climate context" (interview 2, climate-concerned). Another had also heard the term, however, "not related to climate change, but related to greenhouse gas emissions" (interview 20, climate-ambivalent). Likely because the term explicitly referred to climate change, all interviewees did draw a link to climate change when attempting to explain it. Interviewees mentioned reducing greenhouse gases from aviation (interview 22, climate-concerned) and driving (interview 15, climate-concerned). They suggested reducing industry emissions (interview 2, climate-concerned), standardizing mobile phone cables and using renewable energy for heating systems (interview 15, climate-concerned), implementing international trading emission certificates (interview 8, climate-concerned) and changing agriculture (interview 20, climate-ambivalent). One interviewee explained: "It is about carbon neutral production and therefore reducing climate change a bit" (interview 2, climate-concerned). Another said: "For me,

fighting climate change is about mitigating greenhouse gas emissions" (interview 17, climate-ambivalent). Twelve (50%) were unsure about the details. They described the term as "wishy-washy" (interview 22, climate-concerned), "abstract" (interview 14, climate-concerned) and "imprecise" (interviews 14 and 20, climate-ambiguous). Five interviewees (21%) noted that climate change is a process and that they were unsure "whether climate change can even be mitigated" (interview 9, climate-concerned). "It is a permanent process. I can't press a button and say 'now it is five' or 'now it is one or zero' like a radiator" (interview 24, climate-ambivalent). Another also pointed out that "You can reduce a sum, but not a process" (interview 17, climate-concerned). Additionally, an interviewee asked: "It either happens or it doesn't happen. What is it compared against?" (interview 19, climate-concerned). Interviewees also said they preferred simpler wording, such as "reducing" (interview 22, climate-concerned). None expressed mistrust towards the term or sentence.

Five (21%) described the sentence as ambiguous. Twenty (83%) pointed to the nested sentence or length: "The sentence structure is inconvenient, too many commas and subordinate clauses. You can't grasp the content that quickly. The content is not really difficult, but the sentence structure makes it a bit complicated. Could have been worded more simply" (interview 10, climate-concerned). A confused interviewee noted: "This is very, somewhat described stiltedly, this is not very clever, you wouldn't understand this in one go" (interview 17, climate-ambivalent). Interviewees were also unsure about how to interpret terms such as "justice" (interviews 4 and 8, climate-concerned), "sustainable" (interview 8, climate-concerned) or "sustainable development" (interview 19, climate-concerned).

Recommendations Interviewees suggested terms such as "reduction" (interviews 3, 11 and 13, climate-concerned; 17, 18 and 23, climate-ambivalent), "slowdown" or "lowering (of global warming)" (interviews 4, 9 and 22, climate-concerned), "abatement" (interview 5, climate-concerned), and "diminution" (interviews 10, 16 and 22, climate-concerned). To familiarize audiences with the term, it needs to be made clear that mitigation refers to the reduction of greenhouse gases to a level where global temperatures do not further increase. We suggest using phrases from interviewees, such as "slowing down climate change [by reducing emissions]" (interview 17, climate-ambivalent). To clarify details, interviewees recommended mentioning the different types of emissions that are targeted by climate change mitigation in addition to CO_2, including methane (interview 22, climate-concerned) or nitrous oxide (interview 21, climate-ambivalent). We also recommend using short, concise sentences (interviews 3 and 12, climate-concerned).

3.2.6 Sustainable development

Potential confusion This term was ranked as the sixth-most difficult (Table 1). With the exception of one, no interviewees were unfamiliar with the term, or combination of terms. One interviewee said: "I don't remember a concrete event, but I feel that I may have heard it somewhere" (interview 7, climate-concerned). Additionally, 13 (54%) noted that the term is widely used. For nine interviewees (38%), the link to climate change was unclear. Two interpreted this in general terms: "this means sustainable development mainly in the production of consumer goods. Or solar power, green energy. The goal is making this the standard" (interview 5, climate-concerned) and "this is vague. What type of development does it refer to? Is it a type of development that in the long run doesn't lead to whatever type of crises?" (interview 4, climate-concerned). Another one added "Sustainable

development is like making sauerkraut. It is a long-term development, it implies a time period that is as long as possible after these changes have been made" (interview 17, climate-ambivalent). Twelve interviewees (50%) were unsure about the details and did not seem to know what sustainable development referred to. One interviewee said: "What does sustainable development mean? Probably one that doesn't lead to crises in the long run" (interview 4, climate-concerned). Another drew a link to the prevention of nuclear wars: "Sustainable [means] making sure that nothing goes wrong. Or something like that. [That the earth] doesn't become completely littered and uninhabitable for humans. Or making sure that the world doesn't get destroyed by any nuclear wars" (interview 24, climate-ambivalent). One commented that "Well, everyone interprets this differently" (interview 19, climate-concerned). Ten interviewees (42%) referred to industry, mentioning "consumer goods" (interviews 1, 5, 8, 15 and 16, climate-concerned), "agroforestry" (interview 2, climate-concerned), "companies" and "economic growth that doesn't lead to crises" (interviews 4 and 22, climate-concerned), "recycling" (interview 6, climate-concerned), "resources sourced regionally" (interview 16, climate-concerned). For two interviewees, the term implied "[seeing] continued economic growth, but it's less harmful to the environment" (interview 22, climate-concerned) and "growth [that is] possible in the long term, just without evoking any crisis" (interview 4, climate-concerned). Also, five interviewees (21%) perceived the term as a buzzword: "Everyone talks about it. As soon as there is a new company, they are sustainable or develop sustainably, it's a buzzword" (interview 4, climate-concerned) and "sustainability is a big topic. But I guess for many people it just passes by". (interview 21, climate-ambivalent). None expressed mistrust towards the term or sentence.

Four (17%) described the sentence as ambiguous. For example, one complained that it was: "difficult d to understand what the goals are if there aren't any examples" (interview 8, climate-concerned). Another noted that "this is a matter of interpretation" (interview 20, climate-ambivalent). Eleven interviewees (46%) mentioned the nested sentence or length. Interviewees confessed: "To be honest, I think the sentence has no meaning" (interview 22, climate-concerned) and "To be honest, I would have to read it five more times [to understand it]" (interview 18, climate-ambivalent).

Recommendations Six interviewees (25%) requested concrete descriptions about what sustainable development is. They said "I would include an example, such as reducing CO_2" (interview 8, climate-concerned) and "before I evaluate a measure, I need to know what the goal is: reaching some climate targets or becoming CO_2 neutral?" (interview 1, climate-concerned). To prevent the term from being conflated with related terms like sustainable production of goods (interviews 1, 5, 8, 15 and 16, all climate-concerned), communications need to include a short definition. Examples would also be helpful (interview 19, climate-concerned), such as replacing fossil fuel extraction with renewable energy production (interview 5, climate-concerned), or making forestry sustainable (interview 2, climate-concerned).

3.2.7 Abrupt change

Potential confusion This term was ranked as the seventh-most difficult (Table 1). Three interviewees (13%) were unfamiliar with the term, or combination of terms. For example, an interviewee thought that the term occurred "more likely in the context that quick and strong changes are needed for rescuing something. I'm pretty sure that this is not what

this means" (interview 1, climate-concerned). Another interviewee expressed uncertainty about knowing the term: "I'm not sure" (interview 19, climate-ambivalent). For thirteen interviewees (54%), the link to climate change was unclear. One interviewee said: "If I got up and went to the bathroom to apply a ton of makeup to my face, then my dog would say, oh that was an abrupt change" (interview 6, climate-concerned). Another stated: "Well, something changes very suddenly" (interview 24, climate-ambivalent). Seven interviewees (29%) explicitly noted that they were unsure about details. Reasons were that abrupt change could either refer to societal change or to changes in the climate system: "maybe [this is] related to the abrupt changes that are currently going on, concerning the frequency of climate disasters maybe. I don't know. Could also be related to the changes that are expected in terms of peoples' lifestyles and standard of living. I don't know exactly what this refers to" (interview 1, climate-concerned). Also, it wasn't clear to one interviewee (interview 18, climate-ambivalent) whether abrupt change was negative or not. Seven climate-concerned interviewees (29%) related the term to tipping points or struggled explaining the difference between the two: "Abrupt reaction is a good description. I'm also somehow equating the term with tipping point" (interview 14, climate-concerned). According to IPCC definitions, they are not quite the same – abrupt changes are likely to happen after crossing a tipping point (see Table 3). Others referred to climatic changes, affecting weather, climate and ecosystems (interviews 12 and 13, climate-concerned). Some, however, also mentioned societal change needed for mitigating climate change (interviews 1 and 7, climate-concerned). None expressed mistrust towards the term or sentence.

Five interviewees (21%) described the sentence as ambiguous: "Well, this could mean that humanity needs to change in order to mitigate climate change. Or, climate could change abruptly, though to my knowledge, climate changes steadily, but I could be wrong" (interview 14, climate-concerned). More than half (13; 54%) pointed out the nested sentence or length or that they needed to read the sentence several times. One interviewee said: "This sentence is very confusing. Again, it has a huge insertion that makes you forget at the end how the sentence started in the first place" (interview 4, climate-concerned). Another agreed: "All these sentences use subclauses and those make them more difficult to understand" (interview 17, climate-ambivalent). Others complained about jargon, such as "probability" (interview 4, climate-concerned), "abrupt" (interview 19, climate-concerned), or "ocean circulation" (interviews 5 and 8, climate-concerned).

Recommendations Interviewees suggested to replace 'abrupt' with more familiar terms, such as "sudden", "quick", "drastic" (interviews 1, 3, 5, 10, 11, 16, 19 and 23, climate-concerned; 17 and 18, climate-ambivalent), "unexpected" (interview 13, climate-concerned), "critical", "dramatic" (interview 4, climate-concerned) or "extreme" (interview 7, climate-concerned). Communications may benefit from explicit links to changes in the climate system, such as drastic changes towards "high temperatures" (interview 22, climate-concerned), various changes in weather patterns (interviews 10, 12 and 13, all climate-concerned), "ocean circulation" (interviews 1 and 9, climate-concerned), "the entire climate system or future global challenges to humanity" (interview 1, climate-concerned). To clarify details, communications need to explain how the terms 'tipping point' and 'abrupt change' are not synonyms but usually happen consecutively, 'which makes reversion to a previous state impossible' (IPCC 2023, see Table 3; interview 14, climate-concerned). Interviewees also suggested to split or shorten the sentence (interview 9, climate-concerned; interview 21, climate-ambivalent).

3.2.8 Adaptation

Potential confusion This term was on average ranked as the least difficult to understand (Table 1). Everyone was familiar with the term, or combination of terms. For ten interviewees (42%), however, the link to climate change was unclear: "Something needs to be adjusted. A correction, or something needs to be changed" (interview 12, climate-concerned). Another interviewee said: "Adapt to society or something? Or adapt to circumstances … Well, that term can cover many things. My child has to adapt to the fact that I'm on late shift, or some have to adapt to power outage or so" (interview 20, climate-ambivalent). Ten interviewees (42%) were unsure about the details. For example, they used general terms that omitted climate change: "I would say adaptation means reacting to situations or circumstances and then taking action to deal with that situation" (interview 11, climate-concerned). Others expressed uncertainty: "As it stands, I don't think that [people] will understand that this implies substantial change for their daily life" (interview 24, climate-ambivalent). One also confused the term with "integration" (interview 18, climate-ambivalent). Some did link the term to climate change consequences, mentioning that "you just have to deal with all these consequences, I don't know, adapting to rising water levels by building houses differently, building somewhere else" (interview 1, climate-concerned), and "doing modified agriculture, for example, or protecting the coasts better" (interview 4, climate-concerned). Other consequences mentioned were storms (interview 19, climate-concerned), drought (interview 17, climate-ambivalent), and heat (interview 22, climate-concerned). Interviewees also confused adaptation with measures for mitigation. "Maybe, in a climate context, we have to adapt our behaviors, so we won't destroy the climate any further?" (interview 6, climate-concerned). Means mentioned were lowering energy use (interview 3, climate-concerned), recycling (interview 5, climate-concerned), consumer products (interview 1, climate-concerned), or changing mobility (interview 8, climate-concerned). One interviewee explained that the term implies to continue business as usual rather than mitigating climate change: "It suggests that it is possible to just keep doing it" (interview 22, climate-concerned). Interviewees also mentioned adaptation of natural systems: "the first thing that always comes to mind is the polar bears" (interview 16, climate-concerned) or "Adaptation includes how nature adapts. For instance, this year, it was very dry (…). Very little precipitation. Nature adapted. Plants died or had fewer leaves" (interview 17, climate-ambivalent). No one expressed mistrust towards the term or sentence.

Interviewees indicated that the sentence was ambiguous. Two (8%) described the sentence as unclear: "It is not long, but it is very vague" (interview 22, climate-concerned) and "The sentence is not very complicated, but it is not clear" (interview 20, climate-ambivalent). Eleven interviewees (46%) mentioned the nested sentence or length: "I have an issue with these two subclauses … but I can understand it" (interview 7, climate-concerned). This was echoed by others: "You have to read it a few times until you get it. Mainly because of the comma" (interview 23, climate-ambivalent).

Recommendations Interviewees suggested describing explicitly what the term adaptation would mean for people's lifestyles (interviews 1 and 5, climate-concerned; interview 24, climate-ambivalent). Communications also need to link to climate change, by explicitly describing relevant details, including what people need to adapt to. Moreover, communications should point out the necessity of protection against climate change consequences, such as coastal protection or adaptation of agricultural practices (interview 4,

climate-concerned). Interviewees also suggested splitting up the sentence and using parentheses rather than subclauses (interviews 3 and 6, climate-concerned).

4 Discussion

The United Nations' Intergovernmental Panel on Climate Change (IPCC) and other institutions communicate about climate change to international audiences without a background in climate science, including the general public. The terms used in such communications shape how well those communications are understood. Experts therefore recommended the use of more accessible language in IPCC reports. This is important, because those reports are shared by policy makers when addressing public audiences (Brüggemann et al. 2018), and summarized in 'derivative' communications for special audiences such as teachers. Bruine de Bruin et al. (2021) found that Americans struggled to understand key terms from IPCC reports. However, Americans tend to be less concerned about climate change as compared to Germans (Bruine de Bruin and Dugan 2022; Lloyd's Register Foundation 2021) and may have lower reading comprehension skills (OECD 2013). Here, we therefore examined how 24 interviewees from Germany interpreted the German translation of these key terms, including 'tipping point', 'unprecedented transition', 'carbon neutral', 'carbon dioxide removal from the atmosphere', 'adaptation', 'mitigation of climate change/ of greenhouse gas emissions', 'sustainable development', and 'abrupt change'. Although German interviewees rated almost all terms as relatively easy to understand, they struggled to interpret terms. In line with theories of how people make sense of new information, interviewees seemed to draw on their understanding of other contexts – or mental models – to interpret the presented terms (Bruine de Bruin and Bostrom 2013; Reynolds et al. 2010). At least six issues arose in the interviews.

First, interviewees were unfamiliar with terms or the combination of terms. For example, participants noted that they had heard about 'carbon dioxide removal', but not when it linked to the 'atmosphere'. Some were also unfamiliar with the terms 'tipping point' and 'unprecedented transition'. They also noted that the terms 'mitigation' and 'climate change' did not match, and did not know the term 'abrupt change'.

Second, interviewees noted that they did not know how the terms were linked to climate change. This was true for all terms, except for 'mitigation of climate change/ of greenhouse gas emissions', likely because it mentioned climate change as part of the term. Interviewees who had heard of 'carbon dioxide removal from the atmosphere', 'carbon neutral', 'tipping point', 'unprecedented transition', 'adaptation', and 'sustainable development' did not necessarily know what it meant in the context of climate change.

Third, for all terms, interviewees were confused about the details. They associated terms with the wrong climate processes: For example, they linked 'carbon dioxide removal from the atmosphere' to the production of new materials, such as plastic, or energy carriers. They associated 'carbon neutral' with zero CO_2 emissions and 'tipping point' with disaster. Some of our participants' definitions of 'tipping point' also reflected the IPCC definition of the term. 'Unprecedented transition' was related to lifestyle changes. Participants were also confused about how climate change could be 'mitigated'. 'Sustainable development' was sometimes linked to sustainable production of consumer goods only. They also thought that 'adaptation' linked to actions that help mitigating climate change, such as reducing

energy demand, or to natural systems that need to adapt to a changing climate only, but not to humans. Many interviewees explicitly requested details about underlying processes, or concrete examples: For instance, they wanted to know more about the technical means for removing carbon dioxide from the atmosphere and also requested more information about how carbon neutrality could be achieved, or why and how 'abrupt change' occurred in a climate context.

Fourth, interviewees expressed mistrust towards terms and sentences. For example, the term 'carbon neutral' elicited mistrust. 'Carbon neutral' was associated with 'greenwashing'. This possibly links to high-level UN representatives' concerns about presumably 'carbon neutral' governments or non-state actors (UN 2022) and an EU-wide legislation against greenwashing (European Commission 2020). No one mentioned confusion about the overlapping concepts of net zero and 'CO_2 neutrality' (IPCC; 2022, Annex II). Interviewees however thought that this term may be used to trick people about the real carbon emissions associated with a consumer product, and thus described it as fraud. They described the term 'unprecedented transition' as jargon or populist and suspected communicators to use this term for attracting (media) attention. Some also doubted that the word 'unprecedented' was a correct description of climate change, because the climate had already changed in the past. Although it did not explicitly trigger mistrust, 'sustainable development' was labeled as a 'buzzword' because companies could (mis)use it for advertising their products.

Fifth, interviewees found associated sentences ambiguous. All sentences, except for the sentence for 'carbon neutral', were perceived as confusing: This was particularly pronounced for the sentence using the term 'Unprecedented transition' because it did not precisely describe previous changes in climate and relevant time frames. Similarly, the sentence for 'sustainable development' was described as too abstract, and interviewees requested specific examples. Interviewees also requested more details when presented with the sentence about 'abrupt change': They were unsure whether humanity needed to change, or whether the climate itself was changing. Interviewees also complained about unfamiliar jargon and acronyms in sentences, such as "CCS."

Sixth, sentences presented with all terms were perceived as too long. For example, the sentences about 'carbon dioxide removal from the atmosphere' and 'carbon neutral' contained too many subclauses or insertions. Participants also mentioned length in response to the sentence including 'carbon neutral'. They also stated that they had to read the sentence about 'tipping points' or 'unprecedented transition' several times. Participants also mentioned jargon used in sentences, such as 'justice' or 'sustainable' in the sentence about 'mitigation of climate change/ of greenhouse gas emissions'.

4.1 Limitations and future research

Although our German sample included more interviewees who were concerned about climate findings agree with the original US study (Bruine de Bruin et al. 2021). Follow-up surveys will help to assess the prevalence of misunderstanding terms and sentences, and how such misunderstandings vary between different audiences (Bruine de Bruin and Bostrom 2013). These follow-up surveys may compare audiences from different countries with varying degrees of climate change concern, or examine how misunderstandings vary with literacy (OECD 2013), or climate change knowledge (Shi et al. 2016). Such studies could also explore how misunderstandings relate to the type and frequency of media channels people around the world engage with (Treen et al. 2022; Weaver et al. 2022),

as well as for prior exposure to IPCC reports. Because terms and sentences in our study were presented in isolation, future research could also validate whether findings hold when presenting people with longer paragraphs and more context, while probing deeper into how people make sense of such information (Odden and Russ 2019; Swim et al. 2010). Finally, any recommendations provided in this paper need to be empirically tested against original communications to evaluate whether they indeed improve understanding, engagement, and trust, using large, randomized control trials (Bruine de Bruin and Bostrom 2013).

4.2 Implications for climate change communications

In line with previous findings with a U.S.sample (Bruine de Bruin et al. 2021), our findings suggest that German communications about climate change need to use clear language, clarify links to climate change, and present relevant details. Specifically, using clear language involves avoiding jargon and acronyms (Cutts 2013; Rakedzon et al. 2017; Kause et al. 2020), using short sentences (Kadayat and Eika 2020) and words of one or two syllables (Bruine de Bruin et al. 2021; Barkemeyer et al. 2016; McLaughlin 1969). These recommendations may help IPCC authors to communicate in language that their audiences can understand. Our findings are in line with recommendations from the plain language movement (Adler 2012).

Our findings may be especially important for so-called 'derivatives', or communications that adopt central insights from IPCC reports for specific audiences, such as school teachers. In Germany, several platforms such as klimafakten.de or the GERICS climate service center (GERICS 2024) offer scientifically grounded, simple and accessible information about the climate (Schrader 2022). Klimafakten.de also provides evidence-based communication strategies. Some platforms have already started to co-evaluate their content with both climate and communication experts, as well as end users so as to identify barriers to understanding (Schrader 2022).

Additional recommendations for improving climate change communications have been provided by the social science of science communication (National Academies of Sciences 2016; Bruine de Bruin and Bostrom 2013; Morgan et al. 2002; Wong-Parodi and Bruine de Bruin 2017). In addition to recommending simple language, the science of science communication recommends concise summaries, in formats such as videos, short summaries, FAQs, and simple graphs that focus on one key message (Bruine de Bruin et al. 2024). Visual imagery such as photos could be improved by showing real people doing concrete actions rather than staged photo-ops (Corner et al. 2018). Numbers will be easier to understand if they are presented as natural frequencies rather than conditional probabilities, and as absolute rather than relative change (Kause et al. 2020).

Moreover, communication content and sources need to address mistrust (Riet et al. 2020). Trust may be increased by simple climate communications with careful explanations (Taube et al. 2021), transparency about uncertain scientific evidence (Joslyn and Demnitz 2019; Joslyn and LeClerc 2016), and references to the scientific consensus about climate change (Schmid et al. 2020). Trust into communicators can be enhanced by creating a sense of belonging as well as personal stories and humour.

In sum, communications about climate change such as those of the IPCC should be designed in ways that are useful to target audiences. Social science research such as this study provide the necessary scientific evidence to increase transparency in climate change communications.

Supplementary Information The online version contains Supplementary Information available at https://doi.org/10.1007/s10584-024-03725-2.

Acknowledgements We thank Sina Löschke from the IPCC Working Group II's communications team for informing the interview protocol, Neele Bünning for her support during interview analysis and two anonymous reviewers.

Author contributions L.W. planned and conducted interviews, with input from A.K. and W.B.B. and materials from her U.S. study. L.W. transcribed interviews. L.W. and A.K. conducted the data analysis. L.W. and A.K. drafted the manuscript. All authors subsequently revised the manuscript. All authors approved the submitted version.

Funding Open Access funding enabled and organized by Projekt DEAL. This work was supported by internal funding of Leuphana University of Lüneburg (FAF 73100081). The authors declare that no other funds, grants, or other support were received during the preparation of this manuscript.

Data availability English and German interview guidelines are provided in Supplementary Information. The information sheet, full German interview transcripts and the coding system is available via https://osf.io/g8kh9/.

Declarations

Ethics approval and consent to participate The study was approved by the ethics advisory board of Leuphana University of Lüneburg (Votum_EB-Antrag_202205-09-Kause_Klimaterminologie). Participants consented to participate by registering for the interview study in the screener survey.

Consent for publication A detailed information sheet participants received in advance to the interviews stated that their answers would be transcribed anonymously, be made available to other scientists, and anonymous quotes be used in scientific publications.

Competing interests The authors declare no competing interests.

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