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ARTICLE

The differential effects of metaphor on comprehensibility and comprehension of environmental concepts

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Abstract

Metaphors are prevalent in environmental science communication, because they describe complex topics in more familiar terms. Yet, little research has investigated whether metaphors contribute to comprehension in such communication. This experiment (N = 510) disentangles the effects of different metaphor types on comprehension-related outcomes for three environmental concepts (greenhouse effect, carbon footprint, greenwashing). Results showed small but statistically significant effects of some metaphors on perceived text comprehensibility and perceived comprehension, but no effects on actual comprehension. No mediation effects were attested. Science communication could thus benefit from metaphor, but communicators should be careful not to overdo it, nor to overestimate its effectiveness.

Keywords

Environmental communication; Public understanding of science and technology

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1 ▪ Introduction

Climate change, use of natural resources and sustainable consumption are environmental topics that are high on both the political agenda [e.g., European Commission, 2021; Patterson et al., 2017; United Nations, n.d.], as well as the public agenda [Poushter et al., 2022]. Consequently, these topics are prominently discussed in media discourse around the globe [e.g., Barkemeyer et al., 2018; Diaconeasa et al., 2022; Hase et al., 2021; Schäfer & Schlichting, 2014]. Important goals of such environmental science communication are to create awareness and inform audiences about the science involved and its results, and — ultimately — to foster more sustainable or pro-environmental behavior [e.g., Adomßent & Godemann, 2011; de Bakker & Jensen, 2020; Rice & Miller, 2023].

However, environmental science communication does not always reach the intended outcomes [Fischer et al., 2021; Scheufele & Krause, 2019]. One reason why such communication sometimes fails to be successful is because it is concerned with abstract and often complex scientific concepts that non-specialists may not be very familiar with, such as 'carbon dioxide removal', 'ocean acidification', and 'mitigation' [e.g., Bruine de Bruin et al., 2021]. Research has shown that effective communication between science and society may be hampered when it contains such jargon terms, because non-specialist audiences consider them to be relatively difficult to understand [Bullock et al., 2019; Shulman et al., 2020].

To mitigate this problem and make issues more accessible for a target audience, science communication often deploys metaphor [Larson, 2011; Thibodeau et al., 2017]. A well-known metaphor in the context of environmental science communication is that of the greenhouse effect, which explains the way in which gases in the earth's atmosphere regulate the earth's temperature by comparing it to the insulating glass of a greenhouse in which people grow plants. Metaphors draw connections between less familiar concepts (e.g., the processes in the earth's atmosphere) and concepts that non-experts may have at least some experience with (e.g., garden greenhouses). As such, they are hypothesized to make texts easier to understand [e.g., Jaeger & Wiley, 2015; Reijnierse et al., 2015] and to positively affect recipients' knowledge of, attitudes and behavioral intentions towards, as well as engagement with, a topic [e.g., Flusberg & Thibodeau, 2023; Nerlich & Hellsten, 2014; Raimi et al., 2017].

Previous research has shown that metaphors often have a positive effect on persuasion in a range of contexts, among which environmental communication [e.g., Hauser & Fleming, 2021; O'Keefe & Hoeken, 2021; Sopory & Dillard, 2002]. However, relatively little experimental research has investigated the effects of metaphors on recipients' comprehension of environmental concepts [Flusberg & Thibodeau, 2023]. This is surprising, because of two reasons. First, the informative function of metaphor is considered central to its effectiveness in (science) communication [Guy et al., 2013; Lakoff & Johnson, 1980; Sopory & Dillard, 2002]. Second, comprehension can be an important factor in attitude formation and change [e.g., Seel, 2012; Wyer Jr. & Shrum, 2015]. As such, the informative function of metaphor may be key to effective environmental science communication. Our main goal in this paper is therefore to disentangle the effect of environmental metaphors on comprehension-related measures.

2 ▪ Literature review

One of the main reasons why metaphors are a useful tool in science communication is because they allow to describe abstract, complicated and unfamiliar things and situations (the target domain) in terms of more concrete, simpler and/or more familiar things and situations (the source domain) [e.g., Lakoff & Johnson, 1980]. In doing so, metaphors can serve a range of different functions, among which to persuade and to explain [e.g., Beger & Smith, 2020].

Research investigating the persuasive impact of metaphor in environmental science communication generally suggests that metaphors can indeed be persuasive [e.g., Flusberg et al., 2017; Guy et al., 2013; Hauser & Fleming, 2021; Meijers et al., 2019; but see, e.g., Corner & Pidgeon, 2015, for limitations]. Flusberg and colleagues [2017] for instance, found that when climate change was described in terms of a war, participants experienced higher levels of urgency and risk compared to when climate change was described in terms of a race or in non-metaphorical terms (i.e., as an issue). They also found that people were more willing to change their sustainability behavior after having read the text containing the war metaphor. In a similar fashion, a greater proportion of students (but not a more general sample of the Australian public) indicated that we need to 'act now' in response to climate change when they read a metaphorical description about the accumulation of carbon in the atmosphere than when they read a non-metaphorical description of it [Guy et al., 2013]. Finally, Meijers et al. [2019] extended research on the effects of verbal sustainability metaphors to the realm of visual metaphors in the context of recycling. Their findings showed that a campaign using a visual metaphor led to more positive attitudes towards recycling clothes and to higher recycling intentions than a campaign using non-metaphorical visuals.

By contrast, experimental research into the informative function of metaphors in environmental science communication has shown mixed results [Yang et al., 2023]. While some studies show that metaphors, compared to non-metaphorical descriptions, have positive effects on recipients' comprehension of environmental concepts such as climate change and CO_2 accumulation, others do not [e.g., Guy et al., 2013; Jaeger & Wiley, 2015; Volmert, 2014]. For instance, using the source domain of water levels in a bathtub, Guy et al. [2013] tested non-experts' understanding of the target domain of CO_2 accumulation in the atmosphere. They found that participants who had been exposed to the bathtub metaphor were better at estimating the emission rate necessary to stabilize CO_2 emissions by the year 2030 compared to participants who did not read the metaphor. It should be noted though, that despite making better estimations, the majority of participants in the metaphor condition still were not able to provide the correct *exact* emission rate. In another study, Jaeger and Wiley [2015] described the functioning of the greenhouse effect (target domain) either non-metaphorically or by adding information in which it was compared to parking a car in the sun and rolling its windows up or down (source domain). Contrary to Guy et al. [2013], Jaeger and Wiley [2015] found that participants who read the metaphorical text scored lower on comprehension tests than participants who read the non-metaphorical version of the text. Even though metaphors are considered excellent tools to describe complex matters in simpler terms [e.g., Lakoff & Johnson, 1980], providing metaphorical information may thus not necessarily be enough for environmental science communication to be effective [cf. Guy et al., 2013; Nerlich et al., 2010; Smedinga et al., 2023].

Various factors may explain the variation in effectiveness of metaphors for science-related topic comprehension in general, and environmental topic comprehension specifically. First, comprehension-related measures may be operationalized differently [e.g., Jaeger & Wiley, 2015; Stoutenborough & Vedlitz, 2014; Wiley et al., 2018]. In this respect, a distinction can be made between perceived comprehensibility,[1] perceived comprehension, and actual comprehension of a text. Metaphors can increase the perceived comprehensibility of text, in that people consider texts with (more) metaphors less complex than texts without metaphors [e.g., Reijnierse et al., 2015; see also Yang et al., 2023]. Furthermore, previous research has shown that perceived comprehensibility of (non-metaphorical) texts and actual comprehension show medium correlations [Friedrich & Heise, 2025]. It has also been shown that metaphors may positively influence people's *perceived* or *subjective* comprehension of a topic, but not necessarily their *actual* comprehension [e.g., Day & Gentner, 2007; Jaeger & Wiley, 2015; but see Wiley et al., 2018, Exp. 2 for the reverse]. This phenomenon is related to the 'illusion of knowing' [e.g., Yang et al., 2020], which holds that people may overestimate what they think they know or understand about a topic, while their factual knowledge is in fact more limited. This, in turn, might then be taken to suggest that metaphors play a role in people's more shallow representations of the text, but not in their situation models of it — representing deeper levels of comprehension [see Kintsch, 1988; McNamara & Magliano, 2009]. In light of this, we aim to disentangle the effects that environmental metaphors have on perceived comprehensibility, perceived comprehension, and actual comprehension.

A second factor that may explain variation in metaphor effectiveness is concerned with the manipulation of metaphor in experimental texts. In addition to characteristics of a metaphor, such as novelty and aptness [Flusberg & Thibodeau, 2023], the position and form of the metaphor in the text has shown to impact comprehension. For instance, Jaeger et al. [2016] found that participants who read texts about science-related topics in which metaphors were interleaved in the text (but not when they were presented at the beginning of the text) performed better in a comprehension test than participants who read versions of the texts without metaphors. Furthermore, Paris and Glynn [2004] found that people who read texts about science-related topics such as human cells and electrical circuits containing multiple instances of a metaphorical comparison ('elaborate analogies') had the impression that they understood the topic better than those who read texts with a single or no metaphorical instances of a metaphorical comparison. They also showed to be better in remembering information and drawing correct inferences from the text, and assessed their own performance better. These findings thus suggest that extended metaphors that are integrated in text may be most effective in enhancing comprehension.

It should be noted, however, that these studies all focused on educational materials. A range of content-analytical studies have shown that metaphors are also frequently used in science-communication practice outside of this educational context [e.g., Atanasova & Koteyko, 2017; Augé, 2023; Koteyko & Atanasova, 2016; Nerlich & Koteyko, 2010; van der Hel et al., 2018]. Yet, in contrast to the systematic mappings tested in the experiments discussed above (e.g., between characteristics of the source domain factory and the target domain animal cell [Paris & Glynn, 2004]), these studies have found that in more naturalistic contexts, science communicators often use "a complex bricolage of mixed metaphors" [Hellsten & Nerlich, 2011, p. 375].

1. Perceived comprehensibility is also sometimes referred to as relative text complexity, and should be distinguished from readability or text difficulty as an inherent feature of texts [see Friedrich & Heise, 2025].

Mixed metaphors combine metaphorical expressions from multiple, unrelated, source domains to describe a target domain concept [Gibbs Jr., 2016]. For instance, in his 2023 video message to launch the latest IPCC report, UN Secretary-General Guterres said: "Humanity is on thin ice — and that ice is melting fast. (…) The climate time-bomb is ticking." [Intergovernmental Panel on Climate Change (IPCC), 2023], combining reference to the source domains of ice and time-bombs to describe the target domain climate change. While theoretical research and anecdotal evidence suggest that such mixed metaphors may not necessarily be more difficult to process than single source domain metaphors (systematic mappings) [e.g., Gibbs Jr., 2016; Kimmel, 2010], research has not yet investigated if and how the use of single vs. multiple source domain metaphors may impact comprehension of environmental concepts. In light of these observations, we aim to add to the existing literature by not only comparing the effect of systematic mappings versus non-metaphorical language, as is typically done, but by also including the effects of mixed metaphor on comprehension.

Finally, while previous work on the effects of metaphor in environmental science communication examined topics related to climate change and sustainable behavior, these hardly explicitly investigated comprehension of three very topical concepts that often occur in environmental science communication: the greenhouse effect, the carbon footprint, and greenwashing [but see Jaeger & Wiley, 2015]. These three concepts each refer to different aspects related to sustainability: from a natural phenomenon to how individuals, companies and objects contribute to climate change. Including a range of concepts in our study allows to draw more generalizable conclusions about the effect of metaphor in environmental science communication.

There are a number of relevant correspondences and differences between the three concepts that make them particularly interesting to study. In terms of correspondences, first, all three terms are frequently used and consequently may have become so conventionalized that they often are not explained anymore in environmental science communication. Second, the concepts share an important characteristic, namely the fact that they are inherently metaphorical: the greenhouse effect is not about garden greenhouses, but about gases warming the earth's surface; the carbon footprint is not about human footsteps, but provides a way to measure the total amount of emissions, such as CO_2; and greenwashing is not about adding a layer of paint to some object, but about a form of misleading advertising. Furthermore, all three concepts allow for elaborate mappings between their respective target and source domains, so that it is possible to create highly similar versions of our experimental material (with each text describing the meaning, operation, significance and impact of a concept).

In terms of differences, the three concepts clearly each focus on a different aspect related to sustainability, and they use different source domains to describe different target domains. They also each allow for a range of other source domains to be used in the mixed metaphor conditions. In this study, we therefore investigate to what extent these concepts can (still) benefit from metaphorical explanation.

3 ▪ Objective

Taken together, we aim to first investigate whether and how different types of metaphors impact the different comprehension-related aspects. Because the above literature has shown

mixed results for the informative effect of metaphor in (science) communication, and because we extend the metaphor variable to include a third level (i.e., mixed metaphor), we first ask:

RQ1 To what extent does the use of a single vs. multiple source domains vs. non-metaphorical explanation of inherently metaphorical environmental concepts influence participants':

(a) perceived comprehensibility of the text;

(b) perceived comprehension of the information; and

(c) actual comprehension of the information?

Next, we also examine potential mediation effects by asking (see Figure 1 below for a visualization):

RQ2 To what extent do perceived comprehensibility and perceived comprehension (jointly) mediate the possible effects of metaphor type (single vs. multiple source domains vs. non-metaphorical explanation) on actual comprehension of environmental concepts?

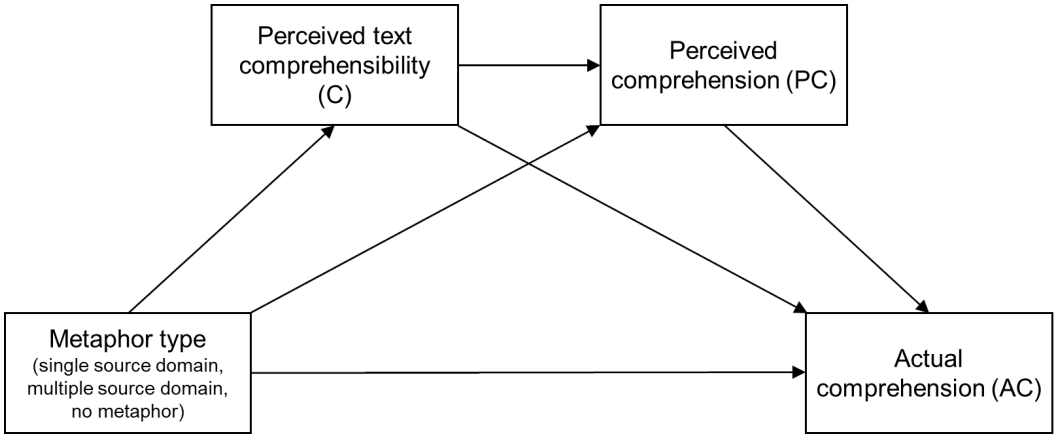

Figure 1. Conceptual model for the mediation effects.

4 ▪ Method

To answer our research questions, we ran an online experiment. The study was approved by the Ethics Review Board of the Faculty of Social and Behavioral Science at the University of Amsterdam before data collection started (FMG-3859).

4.1 ▪ *Design*

We employed a 3 (metaphor types) by 3 (environmental concepts) between-subjects experimental design. First, we manipulated three different metaphor types that were used in texts explaining an environmental concept (i.e., single source domain vs. multiple source domains vs. non-metaphorical explanation). To enhance the external validity of our findings, we also incorporated three different environmental concepts into the study design (the greenhouse effect vs. carbon footprint vs. greenwashing). To make more generalizable claims

about the effectiveness of the different metaphor types across a range of concepts, we collapsed the three environmental concepts in the analyses and only report results on the level of the umbrella term 'environmental concepts' [Clark, 1973].

4.2 ▪ *Participants*

Native-English speaking UK adult participants were recruited in June 2023 through the online data panel Prolific. Following Prolific's ethical rewards principle, participants were compensated with the pro rata equivalent of £9.00/hour. Based on the median survey completion time of ~7 minutes, participants consequently received £1.12 for their participation. The sample size for the experiment was determined a priori using G*Power 3.1 [Faul et al., 2009]. To be able to test the differences between the three conditions with sufficient power (0.80) [Cohen, 1988], based on an effect size of Cohen's $d = 0.27$ [Brugman et al., 2019], we required a sample of 534 participants. To accommodate for a 10% dropout rate, we recruited 580 participants.

A total of 70 participants were excluded from the analysis because they either failed the attention check ($n = 24$; i.e., by incorrectly describing the topic of the text), or took an excessively short ($n = 45$; < 15 seconds; based on M–1 SD) or long amount of time ($n = 1$; > 300 seconds; based on a visual inspection of outliers) to read the stimulus materials. In the end, a total of 510 participants were included in the analyses, of which 64.7% were women (0.8% other). Participants were between 21 and 88 years of age ($M_{age} = 45.24$, $SD_{age} = 13.63$). Of the participants, 58.4% reported having a bachelor's or master's degree, and in terms of their political orientation [1 = *very left-wing* to 7 = *very right-wing*], 48.0% of the participants identified themselves on the left side of the political spectrum [*1–3*], 32.4% in the center [*4*], and 19.6% on the right side [*5–7*]. Table 1 shows the full details of the demographics of our sample.

4.3 ▪ *Stimulus materials*

As previous research has shown that Wikipedia is a regularly-used source for obtaining science-related information among non-student audience segments [Metag et al., 2018], the stimuli used in this experiment consisted of a (fictional) Wikipedia-like entry about the greenhouse effect, the carbon footprint, and greenwashing. The entries were created for research purposes, but mimicked the layout of existing Wikipedia entries as much as possible, which contributes to the ecological validity of our study. As the original Wikipedia entries for the three concepts varied in both length, structure and content, we created new texts based on existing information from official sources such as Wikipedia, NASA and National Geographic. We also prompted ChatGPT [OpenAI, 2023] to provide a range of metaphors to describe our environmental concepts, and used its output for inspiration.

The Wikipedia entries either explained the environmental concepts (1) by using a single source domain that was consistent with the source domain of the inherently metaphorical concept itself; (2) by using multiple different source domains (mixed metaphor); or (3) in non-metaphorical terms. The entries were carefully crafted to ensure similarity in both the factual information and length of the text (around 220 words). The non-metaphorical explanations were composed of three paragraphs containing information about the meaning, operation, significance and impact of the concept. To create the single source domain texts

Table 1. Demographic characteristics of the sample.

Age — years (*SD*; range)	45.24	(13.63; 21–88)
Gender — % (*n*)		
Female	64.7	(330)
Male	34.5	(176)
Non-binary / third gender	0.4	(2)
Prefer not to say	0.4	(2)
Education — % (*n*)		
Did not complete secondary school	0.2	(1)
Completed secondary school	22.4	(114)
Completed vocational school	16.1	(82)
Completed undergraduate (BA)	44.3	(226)
Completed graduate (MA)	14.1	(72)
Completed post-graduate (Ph.D.)	2.9	(15)
Political views — % (*n*)		
Very left-wing	4.5	(23)
Left-wing	20.4	(104)
Somewhat left-wing	23.1	(118)
Neither left-wing nor right-wing	32.4	(165)
Somewhat right-wing	15.1	(77)
Right-wing	3.9	(20)
Very right-wing	0.6	(3)

Note. Total valid N = 510.

and the multiple source domain texts, some parts of the non-metaphorical explanation (around 100 words; roughly 50%) were adapted to metaphorically explain the relevant aspects related to the concepts. The other 50% of the texts remained consistent across conditions.

We now illustrate the creation of the stimulus materials by briefly describing the different manipulations for the text about the greenhouse effect. The materials for these and for the two other concepts examined in this paper are presented in online Appendix A.[2] After an introductory first paragraph (see Figure 2), the greenhouse effect was explained in non-metaphorical terms by describing how greenhouse gases absorb much of the heat of infrared radiation, which raises the atmosphere's temperature. In the third and final paragraph of the text, the impact of having more greenhouse gases in the air was also explained in non-metaphorical terms.

In the single source domain texts, the inherent metaphoricity already present in the term itself (e.g., 'greenhouse') was used for the metaphorical explanation of the concept. Thus, after the introductory paragraph, the greenhouse effect was explained by metaphorically describing it in terms of a garden greenhouse (see Figure 3). The final paragraph described the impact of having more greenhouse gases in the air in terms of adding more insulating material to a greenhouse.

2. All appendices are available at https://osf.io/5bjym/.

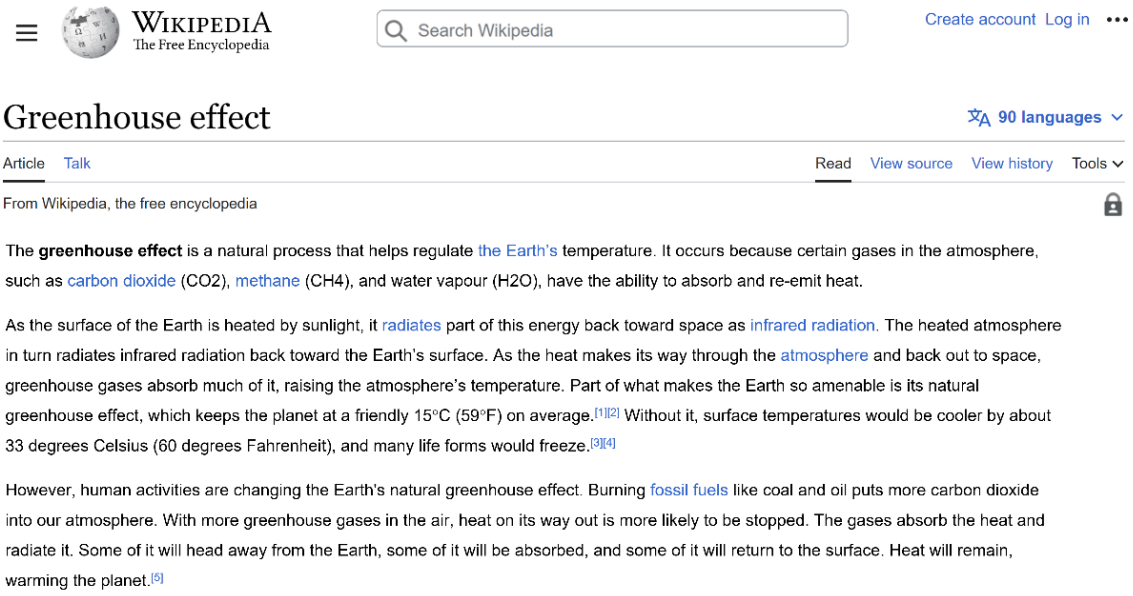

Figure 2. Sample of stimulus material — non-metaphorical explanation.

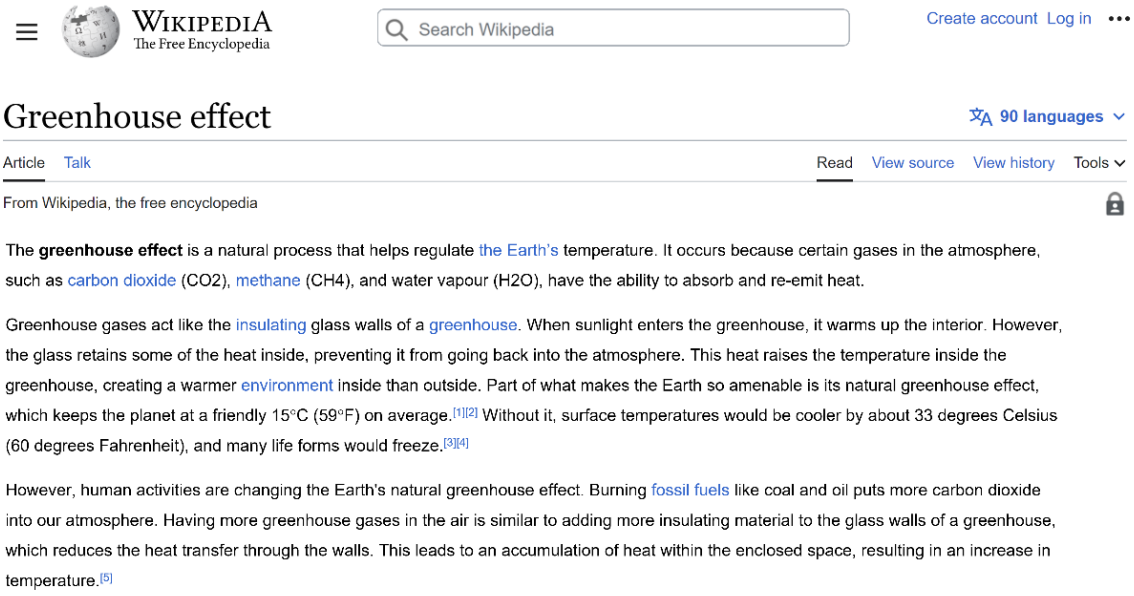

Figure 3. Sample of stimulus material — single source domain explanation.

Finally, to create the multiple source domain versions of the texts, two other metaphors, both unrelated to the source domain embedded in the term itself, were used to explain the meaning, operation, significance and impact of the concepts. The operation of the greenhouse effect (see Figure 4) was explained by metaphorically comparing greenhouse gases to a blanket wrapped around a person to trap a person's body heat. In addition, the impact of the greenhouse effect was explained by metaphorically comparing having more greenhouse gases in the air to an orchestral performance.

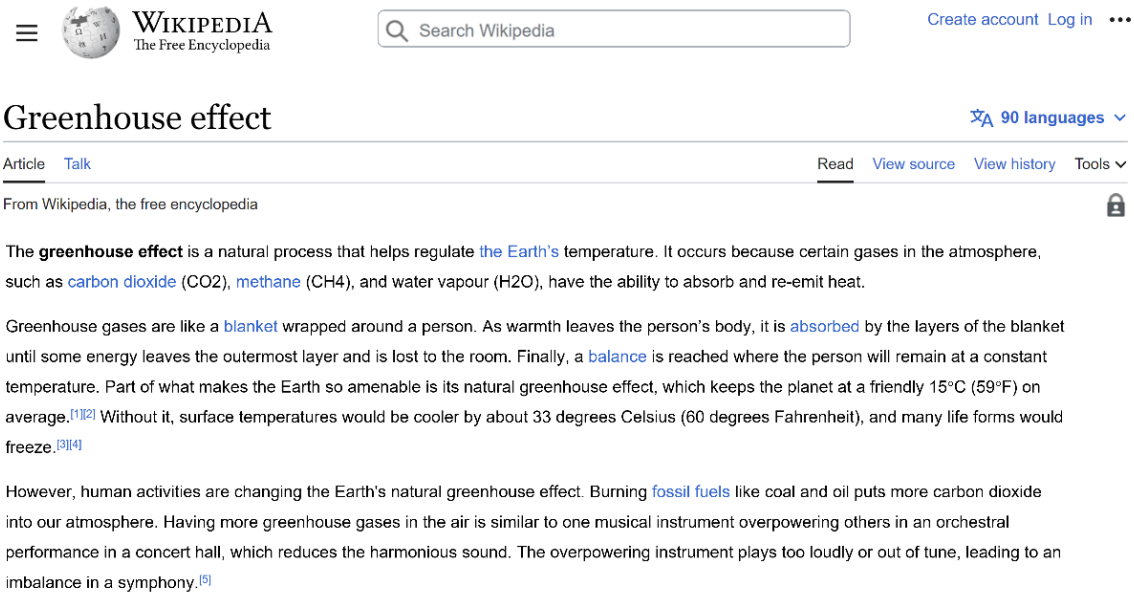

Figure 4. Sample of stimulus material — multiple source domain explanation.

4.4 ▪ *Procedure*

Data were collected online through Qualtrics. After providing consent, sharing their general information (e.g., gender, age), and answering control questions about their environmental concern and (perceived) sustainability knowledge, participants were randomly shown one of the nine experimental conditions. To prevent accidental click-throughs while being exposed to a Wikipedia entry, participants could only go to the next page after 2 seconds. After reading the Wikipedia entry about the environmental concept, participants completed a questionnaire including an attention check, and items measuring the perceived comprehensibility and informativeness of the text, participants' perceived comprehension of the information, their actual comprehension of the information, and their reliance on prior knowledge about the environmental concept when answering these items. After completing all questions, participants were thanked and debriefed.

4.5 ▪ *Dependent variables*

Perceived comprehensibility. Perceived comprehensibility was measured using three of the items from Maes et al. [1996; see also Kamoen et al., 2007] that focus on content-related characteristics of a text. Participants were asked to indicate on three 7-point semantic differential scales to what extent they thought the text they just read was (a) very difficult *[1]*–very easy *[7]*, (b) very complex *[1]*–very simple *[7]*, and (c) very unclear *[1]*–very clear *[7]*. The three items were averaged into an index ($M = 5.12$, $SD = 1.04$, Cronbach's $\alpha = .84$).

Perceived comprehension. Perceived comprehension was measured using three items from Miele and Molden [2010]. Participants were asked to rate their perceived comprehension of the text along several dimensions using three 7-point semantic differential scales. They were asked: (a) 'How well do you feel you understand the text?' *[1 = very poorly, to 7 = very well]*, (b) 'How certain are you that you will answer questions correctly about the

text?' *[1 = very uncertain, to 7 = very certain]*, and (c) 'How confused about the text do you feel?' *[1 = not at all confused, to 7 = very confused]*. After reverse scoring item 'c', the three items were averaged into an index ($M = 5.22$, $SD = 1.03$, Cronbach's $\alpha = .85$).

Actual comprehension. To measure participants' actual comprehension of the text, they were asked to answer five 'fill-in-the-blank' questions about the concept they had read a Wikipedia entry about. While this type of questions is a frequently used format to investigate to what extent people comprehend information [see Shin & Gierl, 2022], it might measure rather shallow levels of text comprehension. To tap into deeper levels of comprehension, we could have asked participants to use their own words to write a short paragraph explaining the concept about which they read a Wikipedia entry, forcing them to rely on the mental model of the text they constructed. Yet, research estimates that one-third to almost half of all participants in online surveys (specifically, MTurk workers) use large language models (AI; e.g., ChatGPT) when completing such open-ended questions [Veselovsky et al., 2023]. Given the unsupervised nature of our online survey, we decided to use a fill-in-the-blanks exercise to tap actual knowledge and as such avoid bogus responses as much as possible.

For each concept, these questions were the same, irrespective of whether a participant had read one of the two metaphorical explanations of the concept, or the non-metaphorical one. The questions measured participants' comprehension of the concept in terms of information that was explicitly stated in the text or had to be inferred from the text, for example: 'The absorption of heat by greenhouse gases contributes to the _____ [*correct answer: warming*] of the atmosphere.' (see online Appendix B for all fill-in-the-blank questions for each concept). The index of participants' actual comprehension of the text was calculated as the sum of all correct answers (0–5; $M = 3.14$, $SD = 1.09$).

4.6 ▪ *Control variables*

We also measured three potential control variables, which we expected might impact our findings. First, we measured environmental concern, as people's level of concern might impact their motivation to carefully read the information in the text [e.g., Liberman & Chaiken, 1996]. Furthermore, we measured both perceived and actual sustainability knowledge (i.e., of sustainability in general rather than a specific concept), as previous research has shown that prior knowledge about a topic may influence learning [e.g., Shapiro, 2004; Wiley et al., 2018].

Environmental concern. To control for participants' prior environmental concern, they were asked to what extent they agreed with the following three items from Hartmann and Apaolaza-Ibáñez [2012] on a 7-point Likert scale *[1 = completely disagree, to 7 = completely agree]*: (1) 'Mankind is severely abusing the environment', (2) 'There are limits to growth beyond which our industrialised society cannot expand', and (3) 'Humans must live in harmony with nature in order to survive'. The three items were averaged into an index ($M = 5.86$, $SD = 0.84$, Cronbach's $\alpha = .67$).

Perceived sustainability knowledge. To control for participants' perceived knowledge about sustainability, they were asked with one item from Malka et al. [2009] on a 7-point Likert scale *[1 = nothing, to 7 = a lot]*: 'How much do you feel you know about sustainability?' ($M = 3.86$, $SD = 0.87$).

Actual sustainability knowledge. To control for participants' actual sustainability knowledge prior to the study, they were asked to answer seven multiple choice questions

[adapted from Leiva-Brondo et al., 2022; Zwickle et al., 2014] about various sustainability-related topics. Each item asked a factual question with only one correct answer. Five answer options were given including a 'Don't know' option. The index of participants' prior sustainability knowledge was calculated as the sum of all correct answers (0–7; $M = 4.63$, $SD = 1.51$; see online Appendix B for all multiple choice questions).

5 ▪ Results

Access to the data, syntax, and output is provided on the Open Science Framework (OSF): https://osf.io/5bjym/.

5.1 ▪ *Randomization checks*

Before answering the research questions, randomization checks were performed to examine whether participants were evenly distributed across the three (non-)metaphorical explanation conditions regarding relevant individual characteristics. This was confirmed in case of gender ($\chi^2(6) = 7.06$, $p = .32$), age, ($F(2, 507) = 2.29$, $p = .10$), level of education ($\chi^2(10) = 14.04$, $p = .17$), political ideology ($F(2, 507) = 0.92$, $p = .40$), environmental concern ($F(2, 507) = 0.86$, $p = .43$), perceived sustainability knowledge ($F(2, 507) = 0.10$, $p = .91$) and actual sustainability knowledge ($F(2, 507) = 0.06$, $p = .94$). Participant groups were thus relatively homogeneous, enabling us to attribute variations in outcome scores between conditions to the manipulations with sufficient confidence. This also meant that the actual statistical analyses could be conducted without any of these variables as covariates.

5.2 ▪ *Manipulation check*

All Wikipedia entries for a specific environmental concept were meant to provide the same information about the meaning, operation, significance and impact of that concept, albeit in either metaphorical or non-metaphorical terms. Nevertheless, some concepts could be more complex than others, resulting in differences in perceived informativeness between the Wikipedia entries for the different concepts. We aimed to circumvent this by having participants indicate the informativeness of the text on one 7-point semantic differential scale (*[1] not at all informative–[7] very informative*; Pasadeos [1990]; $M = 5.69$, $SD = 0.92$).

Although all texts were considered relatively informative, perceptions of informativeness indeed significantly differed between the concepts ($F(2, 506) = 4.23$, $p = .02$, $\eta^2_p = .016$). Pairwise comparisons with a Bonferroni correction showed that the greenhouse effect texts ($M = 5.81$, $SE = .07$) scored significantly higher than the carbon footprint texts ($M = 5.53$, $SE = .07$, $p = .02$). Scores for the greenwashing texts ($M = 5.74$, $SE = .07$) did not significantly differ from those of the greenhouse effect texts ($p = 1.00$) nor the carbon footprint texts ($p = 0.11$). Given the difference observed, the concept condition was added as a covariate in the subsequent analyses to be able to draw general conclusions about the language effects of interest that would not be limited to a specific environmental concept.

We also checked whether the (non-)metaphor conditions would differ in informativeness ($F(2, 506) = 4.08$, $p = .02$, $\eta^2_p = .016$). The non-metaphorical texts ($M = 5.82$, $SE = .07$) were perceived as significantly more informative than the multiple source domain texts ($M = 5.54$,

SE = .07, *p* = .02). However, this could be due to the inherent nature of the latter text type (i.e., using multiple metaphorical comparisons could cause confusion). We therefore did not control for informativeness in subsequent analyses. No other significant differences in informativeness were found between the (non-)metaphor conditions (single source domain *M* = 5.74, *SE* = .07).

5.3 ▪ *Main effects on the comprehension-related outcomes*

To answer RQ1, we conducted three separate Analysis of Covariance (ANCOVA) tests with (a) perceived comprehensibility of the text, (b) perceived comprehension of the text, and (c) actual comprehension of the environmental concept as the dependent variable,[3] the (non-)metaphor explanation conditions as the independent variable, and environmental concept as a covariate.

For perceived comprehensibility of the text (RQ1a), we found a statistically small, but significant effect of condition ($F(2, 506) = 7.37$, $p < .001$, $\eta^2_p = .03$). Pairwise comparisons with a Bonferroni correction showed that the metaphorical conditions containing a single source domain (SSD) scored significantly higher (*M* = 5.35, *SE* = .08)[4] than both the conditions containing multiple source domains (MSD; *M* = 5.07, *SE* = .08, *p* = .03) and the non-metaphorical explanation conditions (*M* = 4.94, *SE* = .08, *p* < .001). No statistically significant difference was found between the non-metaphorical and MSD explanations (*p* = .66).

A similar pattern of results was found for participants' perceived comprehension of the text (RQ1b): we found a small, but statistically significant effect of condition ($F(2, 506) = 7.76$, $p < .001$, $\eta^2_p = .03$). Results of the pairwise comparisons with a Bonferroni correction demonstrated that the SSD conditions scored significantly higher (*M* = 5.44, *SE* = .08) than the MSD conditions (*M* = 5.18, *SE* = .08, *p* = .04) as well as the non-metaphorical conditions (*M* = 5.02, *SE* = .08, *p* < .001). Again, the difference between the non-metaphorical and MSD conditions was not statistically significant (*p* = .43).

In terms of participants' actual comprehension of the text (RQ1c), differences between the conditions failed to reach the conventional threshold for statistical significance by less than a decimal ($F(2, 506) = 2.97$, $p = .052$, $\eta^2_p = .01$). Pairwise comparisons with a Bonferroni correction confirmed that the scores for the SSD conditions (*M* = 3.08, *SE* = .08) and MSD conditions did not significantly differ (*M* = 3.05, *SE* = .08, *p* = 1.00). There was also no significant difference between the SSD conditions and non-metaphorical conditions in actual comprehension scores (*M* = 3.30, *SE* = .08, *p* = .15). The non-metaphorical conditions scored marginally significantly higher than the MSD conditions (*p* = .076). However, the confidence interval of the mean difference contained zero (95% CI[–.02, 54]), suggesting that there is no true difference between the conditions.[5]

3. For the correlations between the comprehension-related outcomes, see online Appendix C.
4. All reported means are adjusted for concept. All raw means for each of the three (non-)metaphor conditions as well as per each of the nine experimental conditions are reported in online Appendix C.
5. Due to space constraints, we report exploratory analyses that try to explain these findings in online Appendix D. These analyses are conducted based on additionally measured variables that tapped into the knowledge resources participants indicated to have used when answering the actual comprehension questions (i.e., prior knowledge, logical thinking, information in the text).

5.4 ▪ *Relationships between comprehension-related outcomes*

RQ2 asked what precisely would be the relationship between perceived text comprehensibility, perceived comprehension, and actual comprehension. We answered this question by conducting Hayes sequential mediation analysis with model 6 and 5,000 bootstraps [Hayes, 2017]. We used actual comprehension as the outcome variable and perceived comprehensibility and perceived comprehension as sequential mediators. Because we had three experimental conditions, multicategorical indicator coding was necessary. When this is the case, a reference category needs to be selected. Given the differences found in the main effects analyses, we chose the SSD conditions as the reference. This allowed us to compare the indirect effects on actual comprehension between the SSD and non-metaphorical explanation conditions on the one hand, and the SSD and MSD conditions, on the other.

The results showed neither direct nor indirect effects. The confidence intervals of all tested indirect effects contained zero, see Table 2. This means that no evidence was found for the idea that there could be indirect effects of the conditions on actual comprehension through perceived text comprehensibility and perceived comprehension of the text. Higher scores on perceived text comprehensibility led to higher scores on perceived comprehension (estimate = .75, *SE* = .03, 95% CI[.70, .81]). However, neither higher scores on perceived text comprehensibility (estimate = –.05, *SE* = .07, 95% CI[–.19, .10]) nor higher scores on perceived comprehension (estimate = .09, *SE* = .07, 95% CI[–.06, .23]) led to higher scores on actual comprehension.

Table 2. Results for the indirect effects analysis.

Effect	*Estimate*	*SE*	*Lower CI*	*Upper CI*
Comparison: SSD versus non-metaphorical				
Condition → C → AC	.02	.03	–.05	.09
Condition → PC → AC	–.01	.01	–.04	.01
Condition → C → PC → AC	–.03	.02	–.08	.02
Comparison: SSD versus MSD				
Condition → C → AC	.01	.02	–.03	.07
Condition → PC → AC	.00	.01	–.03	.01
Condition → C → PC → AC	–.02	.02	–.06	.01

Note. C = text comprehensibility, PC = perceived comprehension, AC = actual comprehension.

5.5 ▪ *Robustness checks*

Because Shapiro [2004] recommended controlling for prior knowledge in studies that test for knowledge and comprehension effects, we also conducted robustness checks by rerunning the ANCOVAs as well as the sequential mediation analysis with sustainability knowledge as a covariate. Results of these checks showed that the study's conclusions were not impacted (see files output on https://osf.io/5bjym/).

6 ▪ Conclusion & discussion

In this paper, we set out to disentangle the effects of different metaphor types on comprehension-related outcomes in the context of environmental science communication. First (RQ1), we found small but statistically significant effects showing that metaphors that draw from the same source domain as the inherently metaphorical concepts under investigation (i.e., greenhouse effect, carbon footprint, greenwashing) positively affect both perceived comprehensibility of the text as well as perceived comprehension, but not actual comprehension of the concept, compared to multiple source domain metaphors or non-metaphorical explanations of the concept. We also investigated the relationship between the three comprehension-related outcomes (RQ2). Although we found that higher scores for perceived comprehensibility of the text correlated with higher scores for perceived comprehension, no indirect effects of metaphor use through both comprehension-related outcomes on actual comprehension were found.

Our findings are in line with previous research suggesting that the use of metaphors, compared to non-metaphorical language, may make environmental concepts more accessible for non-expert audiences [e.g., Flusberg & Thibodeau, 2023; Larson, 2011; Nerlich & Hellsten, 2014]. They are also in line with previous findings by showing that metaphors increase certain aspects of people's comprehension of science-related concepts [e.g., Guy et al., 2013]. One main contribution of our work is that we further specify these general effects by making a distinction between different types of metaphors and different comprehension-related measures. Below, we interpret our findings in light of the existing literature, and provide some first suggestions for future research into comprehension-related effects of metaphors in science communication contexts.

6.1 ▪ *Metaphors influence comprehension-related outcomes differently*

In our study, we focused on informative texts in the form of Wikipedia entries. The main communicative goal of Wikipedia is to provide information, and previous research has shown that many people use Wikipedia to learn more about unfamiliar (science-related) concepts [Metag et al., 2018]. Our findings confirm previously found positive effects of metaphor in science communication on perceived text comprehensibility and perceived comprehension [e.g., Jaeger & Wiley, 2015], and extend these beyond the context of education and to a non-student sample. More importantly, we further specify these findings by showing that the effect of metaphors occurs in certain conditions, i.e., when metaphorical explanations consistently refer to the same source domain. Our findings furthermore contribute to the question of whether metaphors also lead to increased actual comprehension [Wiley et al., 2018] by showing that in the particular context of our experiment — i.e., inherently metaphorical environmental concepts, general audience sample — this does not seem to be the case. Participants in our study had the feeling that they understood the text better when (single source-domain) metaphors were used compared to mixed or no metaphors, but the presence of metaphor did not contribute to their actual understanding of the environmental concepts. This, in turn, suggests that metaphors may primarily have perception effects instead of actual learning effects.

The fact that we found that metaphors did not contribute to actual comprehension is even more interesting when considering the way in which we operationalized the actual comprehension scale. In fact, the fill-in-the-blanks task that we used may have tapped rather

superficial information retrieval from the stimulus materials (factual knowledge). Our findings suggest that metaphors do not contribute to such relatively simple comprehension tasks, but it remains an open question whether they *do* affect deeper levels of text comprehension [see Kintsch, 1988; McNamara & Magliano, 2009]. Given issues with use of AI in open-ended online survey questions [Veselovsky et al., 2023], one way to investigate this matter is by inviting participants to the controlled setting of a research lab instead of having them participate online. In the lab, a range of other options to tap comprehension would also be available, such as think-aloud protocols, in-depth interviews, and TalkBack chains [Aubrun et al., 2006].

In our study, participants' scores were slightly higher for perceived comprehension than for actual comprehension,[6] suggesting that participants somewhat overestimated their comprehension ['illusion of knowing'; Yang et al., 2020]. At the same time, however, it should be noted that both types of comprehension scores were somewhat above the mid-point of the scale, suggesting that people understood quite a bit about the topics. Previous research argues that comprehension can play a key role in attitude formation and change [e.g., Seel, 2012; Wyer Jr. & Shrum, 2015], but it remains an open question to what extent differences between perceived and actual knowledge of environmental concepts actually influences people's sustainability attitudes. On the one hand, it has been shown that overestimation of understanding may positively influence attitudes and behavioral intentions because people often rely on heuristics instead of elaboration to form and change attitudes [e.g., Yang et al., 2020]. On the other hand, Stoutenborough and Vedlitz [2014] warn for the risk of overestimation as they found that people who *thought* they knew a lot about climate change had lower climate change risk perceptions than people who *actually* knew a lot about it. This raises important questions about the role of perceived versus actual comprehension for future research on environmental communication, and science communication more generally.

6.2 ▪ *Metaphor type matters in effective environmental science communication*

Results of our study show that it is not metaphor in general that has a positive influence on (some) comprehension-related outcomes, but that type of metaphor matters: for perceived comprehensibility and perceived comprehension, the single source domain metaphors yielded higher scores than the multiple source domain metaphors and the non-metaphorical explanation. As such, our findings corroborate previous research showing that elaborate analogies are more effective than non-metaphorical language [Paris & Glynn, 2004]. In addition, our work also extends this previous finding by further specifying that — at least in the context of environmental science communication — domain-consistent metaphor use is more effective than mixed metaphor.

One of the reasons why we found a difference in effectiveness between single and multiple source domain metaphors may be that shifting between source domains from one paragraph to the next disrupted participants' processing flow [cf. Friedrich & Heise, 2025; Shulman et al., 2020]. Previous work on mixed metaphor has mostly considered more proximate combinations of source domains, i.e. within paragraphs, sentences, or even clauses [e.g.,

6. Note that scores for perceived comprehension were measured on a 7-point scale, while scores for actual comprehension were measured on a 5-point scale. This implies that scores have been transformed before making the direct comparisons mentioned here.

Kimmel, 2010], and suggested that mixing source domains would not cause any problems for readers [see Gibbs Jr., 2016]. In our experiment, we manipulated mixed metaphor at the paragraph level, with each paragraph only referring to one source domain. Even if some of the alternative source domains, such as the blanket metaphor for the greenhouse effect, were either quite well-known and/or considered apt in and of themselves [Bales et al., 2015; Flusberg & Thibodeau, 2023], the shift between source domains may have been too sudden. At the same time, however, it should be noted that mean scores on comprehensibility and perceived comprehension for the multiple source domain conditions were not that different from those for the single source domain conditions in that both were positioned well above the mid-point of the 7-point scale. This suggests that while mixed metaphors may not have additional benefits compared to non-metaphorical language, they also do not negatively affect comprehensibility and perceived comprehension.

Another possible reason for the attested difference between the single and multiple source domain metaphors may be due to our selection of source domains. For the single source domain conditions, this selection was determined by the inherently metaphorical concepts under investigation. By also including a multiple source domain condition in our study design, we were able to mimic science communication practice in which mixed metaphors are common [e.g., Hellsten & Nerlich, 2011]. In our multiple source domains texts, however, our choice of source domains was somewhat eclectic in the sense that we used diverse source domains that we considered appropriate to describe certain aspects of the concept. Possibly, some of these selected source domains resonated less well with participants, for instance because they considered the metaphors to be less familiar or less apt [Flusberg & Thibodeau, 2023; Thibodeau et al., 2017; see Brugman et al., 2022].

6.3 ▪ *Limitations due to the sample used*

Previous research has shown that people with high prior knowledge about a science-related topic may benefit less from the presence of metaphors than people with low prior knowledge [e.g., Jaeger et al., 2016; Wiley et al., 2018]. As we studied rather well-known environmental concepts and our participants possessed relatively high levels of prior knowledge (Ms $\geq$ 4.63),[7] this could help explain why our participants did not really benefit from the presence of metaphor. It might be the case that metaphors are more effective for participants with less prior knowledge, and for topics about which the target audience does not yet know much, such as ‘tipping point’ or ‘mitigation’ [see Bruine de Bruin et al., 2021]; a matter future research can explore.

Finally, while we extended previous research by moving away from student samples, it should also be noted that we surveyed a rather specific target group. All our participants were British citizens who grew up speaking English. The majority identified as female, and they were relatively highly educated, considered themselves relatively left-wing politically speaking, and were quite concerned about the environment. Participants were modest in their estimates of how much they knew about sustainability, but their actual sustainability knowledge was quite high. It is very well conceivable that different audience segments [Schäfer et al., 2018] react differently to texts about environmental concepts with or without metaphor — something future research might explore as well.

7. The fact that people in the different (non-)metaphor conditions did not differentially rely on the information provided in the text to answer the actual comprehension questions (see Appendix D) provides further support for this interpretation.

6.4 ▪ *Practical implications*

In this study, we have shown that science communication about environmental concepts can indeed benefit from metaphor use. Even if the observed effect sizes were rather small, they may still be impactful when applied to large numbers of people [see Flusberg et al., 2017, p. 779]. Science communicators should therefore be careful in selecting and using metaphor, because a) we only found positive effects for single source domain metaphors but not for multiple source domain metaphors, and b) actual comprehension was neither directly nor indirectly affected.

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