Overcoming heuristics that hinder people's acceptance of climate-change-mitigation technologies

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Keywords: climate protection, climate change mitigation technologies, intervention evaluation, restriction heuristic, vignette methodology

1 Abstract

The overall research objective of the present study is the investigation of the effects of a strongly expressed restriction-oriented climate change mitigation heuristic (SER heuristic) on people's attitudes towards and acceptance of climate change mitigation technologies such as Carbon Capture and Utilization (CCU). Furthermore, we want to examine the effects of a scenario-based communication intervention approach on the promotion of a supportive attitude towards and acceptance of CCU, especially referring to people characterized by a SER heuristic.
Against this background, we present empirical findings based on an online experiment including a scenario-based intervention in an initial sample of 401 German participants. In line with our expectations, our findings show that participants characterized by a SER heuristic report a significantly lower supportive attitude towards CCU as well as a lower acceptance of CCU, compared to participants who are not characterized by a SER heuristic. Furthermore, our findings imply the examined scenario-based communication intervention approach to be an effective tool for the promotion of participants' supportive attitudes towards CCU and acceptance of CCU. Taken together, the present study provides further valuable insights for the promotion of people's supportive attitude towards as well as of their acceptance of necessary new climate change mitigation technologies such as CCU.

2 Introduction

In order to keep global warming below 2°C, as specified in the Paris Agreement, global GHG-emissions must be reduced by 27% from 2019 levels by 2030. The Intergovernmental Panel on Climate Change (IPCC) has made it clear, that although this target is still achievable in principle, it requires immediate and effective action, including technological measures such as the creation of carbon sinks (IPCC, 2022). These measures require not only the development of innovative technologies, for example for Carbon Capture and Storage (CCS) or Carbon Capture and Utilization (CCU) (IPCC, 2022, 2023; Napp & Mazur, 2017), but also the social acceptance of these technologies for their effective use. The implementation of measures to comply with the international climate agreement requires a transformation of our society not only towards more sufficiency, but rather towards a net-zero society (IPCC, 2018), in which the remaining, unavoidable anthropogenic emissions are counteracted by anthropogenic decomposition (storage in carbon sinks). Even if demand is drastically reduced (e.g. by reducing consumption and promoting the circular economy), products (including carbon-neutral product alternatives) must still be manufactured, albeit in smaller quantities (Perišić et al., 2022; Stegmann et al., 2020). Bioeconomic solutions are therefore concerned as they promise to substitute fossil resources through renewable raw materials in industrial and energy production, in order to achieve a shift from economic production towards a bio-based economy (Böcher et al., 2020). The urgently needed transformation of our society must therefore be seen as both a technical and a societal challenge. The societal challenge in this respect relates not only to strengthening sufficient lifestyles, but also to the acceptance of particularly high-impact, innovative technologies (e.g., CCS and CCU).

2.1 Relevance of Climate Change Mitigation Technologies

Against the backdrop of an envisaged transformation towards a net-zero society, great hope lies in the potential of climate change mitigation technologies (CCMT), which bind greenhouse gases through physical, chemical and biological processes and store them in the long-term. CCU and CCS are at the heart of current solutions for capturing as much CO_2 as possible from fossil-based processes (Sunaryo et al., 2023). The CO_2 captured in the process can either be stored (storage) or used directly as a carbon source (utilization) to prevent the CO_2 from reaching the atmosphere and contributing to climate change. CCU goes beyond pure sequestration and aims to convert the captured carbon into products, thus creating a circular carbon economy (Leung et al., 2014).

Particularly among some environmental organizations and activists, CCMT are discussed controversially. This is related to the traditionally critical attitude of environmental NGOs towards new technologies. CCS in particular is discussed very critically here, while CCU is viewed rather positively overall. A joint press memo of Greenpeace Germany, Friends of the Earth Germany (BUND) and others (Greenpeace, 2024) criticizes CCS as a bogus solution inter alia by preventing the phase-out of fossil fuels and the shift towards a circular economy. On the other hand, other German environmental protection organizations, such as NABU and WWF, have recently changed their minds about carbon capture and now consider CCMT as necessary complimentary solutions for climate protection (BDI et al., 2024). This may be due to the differentiating attitude of environmental associations in the course of concepts of ecological modernization (Mol, 2000).

2.2 Acceptance of climate change mitigation technologies

The basis for the acceptance of CCMT within the population of the European Union (EU) - and thus of people from countries that have a significant impact on global climate change - appears to be sound (European Commission, 2023; BMUV/UBA, 2023).

Environmental psychology research already provides a series of empirical findings on psychological and situational predictors of pro-environmental behaviors, in particular, curtailment behaviors: We know about the impact of norms, values and beliefs on behaviors such as private energy consumption, choice of transport, or food consumption (Bamberg et al., 2007; Fritsche et al., 2018; Klöckner, 2013; Steg et al., 2014; Stern, 2000; Thøgersen, 2006). In comparison, the evidence is relatively limited regarding potential factors (e.g., innovativeness or openness to change) influencing the acceptance of CCMT (Baum et al., 2024), which are particularly relevant when it comes to impact. More research on the acceptance of these technologies and the effectiveness of impact-related knowledge transfer is therefore needed in this context.

However, it cannot be taken for granted that information about the potential of these technologies will lead to greater acceptance among all groups of people who are seriously concerned about climate change, and that existing motivations to realize a sufficient lifestyle will simply be supplemented by additional support for innovative CCMT. The results of Matthies et al. (2023) even tend to indicate that the intention to realize a sufficient lifestyle and the acceptance of CCMT might be based on very different heuristics, which can also hinder each other (see 2.3).

2.3 Climate Change Mitigation Heuristics: Restriction versus Optimization?

Heuristics have been addressed as a research topic in various disciplines for 50 years, and the definitions are correspondingly diverse and sometimes vague (Hjeij and Vilks, 2023). In psychology, heuristics are defined as cognitive processes that enable people to make a quick decision by consciously or unconsciously ignoring parts of the available information (Gigerenzer et al. 2011; Korteling et al., 2023). This becomes particularly relevant in more complex decision-making situations. Kahneman (2011) defines heuristics as "a simple procedure that helps find adequate, though often imperfect, answers to difficult questions" (Kahneman, 2011, p. 98).

Based on Simon's (1955) research on bounded rationality, Gigerenzer developed the concept of positive ecological rationality. Instead of dealing with the tendency to fail or the claimed irrationality of human thinking in complex situations, he was interested in the human ability to select heuristics like a tool from an adaptive toolbox in order to solve problems quickly and intelligently in a complex world characterized by uncertainties (Gigerenzer, 2008). A heuristic is considered ecologically rational if it is best adapted to the context or surrounding ecosystem (Gigerenzer, 2015). The tools from this adaptive toolbox, i.e. the heuristics, are not limited to assumptions, methods and rules, but can also include social rules and consistent beliefs that help to simplify and accelerate decision-making processes in complex situations.

When it comes to pro-environmental behavior and decision-making in this context, we are also dealing with complex situations: there are non-linear, linear and noisy relationships between inputs and outputs, decisions are interrelated and can have ambiguous and cumulative outcomes, and our environment can change as a result of the decisions we make, but may also change autonomously (Osman, 2010).

Accordingly, heuristics have also been shown to be relevant in the context of pro-environmental behavior, e.g., when choosing food based on its environmental impact (Wassmann et al., 2024) or when processing green advertising (Santa and Drews, 2023).

Following this understanding and in line with Matthies et al. (2023), we understand climate-change-mitigation heuristics as assumptions or consistent beliefs that guide human judgments about the appropriateness of climate-friendly behavior.

Restriction Heuristic to Mitigate Climate Change

The study by Matthies et al. (2023) demonstrated that a heuristic, which is closely linked to the tradition of the environmental protection movement and was essential in driving forward the commitment to nature conservation and climate protection, is now affecting the acceptance of high-impact climate protection mitigation technologies: the restriction heuristic. This heuristic is rooted in concerns about excessive consumption and limited resources.

The publication of the Club of Rome's report 'The Limits to Growth' (Meadows et al. 1972) launched a controversial debate on the role of Western economic systems and their narrative of unlimited growth as the main cause of the environmental crisis. This important discourse gave impetus to the environmental movement of the 1970s, which advocated for sustainable development and a more sufficient way of life, thus challenging the prevailing global hegemony of the growth paradigm of the 1950s and 1960s (Schmelzer, 2017). The narrative or heuristic of frugality and restriction gained momentum particularly in response to the oil crises of the 1970s, that exposed the vulnerabilities of fossil fuel-dependent economies and the increasing scarcity of resources. The environmental movements responded by promoting practices such as recycling, energy conservation, and sustainable living as alternatives to the prevailing culture of consumerism and overconsumption. This sufficiency or restriction heuristic was further developed in the late 1980s and, in addition to considerations of sufficiency, also included questions of a fair global distribution of development opportunities (Brundtland, 1987) and discussions on consequences of carbon emissions. In line with the global equity perspective, the budget approach, particularly in the context of the Kyoto Protocol, revolves around the concept of allocating carbon emission 'budgets' to different countries based on their historical contributions to greenhouse gas emissions and their respective mitigation capabilities. In essence, the budget approach seeks to distribute the burden of emission reductions fairly, taking into account historical emissions and the capacity of countries to adapt to and mitigate climate change (Messner et al., 2010). Matthies et al. (2023) assume that a generalized heuristic of restriction has emerged from this discourse, which also integrates the moral obligation to restrain, as a kind of compensation for historical overconsumption (Barclay et al., 2015). Although this restriction heuristic is effective in limiting and compensating for individual overconsumption, the latest IPCC report (2022) shows that sufficiency measures alone will not be adequate to mitigate climate change; economic instruments and new technologies are urgently needed. In this context, however, the results of Matthies et al. (2023) show that a dominant (very strong) restriction heuristic can become an obstacle to people's acceptance of newer and highly effective technologies.

Optimization Heuristic to Mitigate Climate Change

Matthies et al. (2023) contrast the heuristic of pure restriction and refraining with a heuristic that focuses on high-impact behaviors (optimization heuristic). The results indicated that this optimization heuristic not only supports an openness to effective and new behaviors to mitigate climate change, but also proves to be the more relevant heuristic for climate change mitigation behavior in general. This optimization heuristic is characterized by an active search for solutions and an openness to different as well as technology-related strategies. This heuristic does not represent a counterproposal that focuses exclusively on technical solutions, but rather an extended heuristic that is aimed at effective climate protection strategies and technologies without refraining from sufficiency strategies.

This raises the question of how individuals with a very dominant restriction heuristic might be able to shift towards an optimization heuristic.
The keen problem awareness among people with a dominant restriction heuristic suggests that they have considerable potential to engage in climate protection measures, which makes them particularly interesting. What might hinder the transformation of the restriction heuristic in the direction of an optimization heuristic? What concerns or fears could this be based on?

The resistance against technological solutions may be related to the history of the environmental movement itself (see above), i.e. to the experience of the various generations of the environmental movement that the narrative of sufficiency could only be introduced into the social discourse characterized by the growth paradigm with great effort (Schmelzer, 2017). Strategies to promote innovative CCMT such as CCU or CCS may inadvertently raise fears that they are primarily aimed at maintaining current living standards without seriously tackling climate change. This perception risks undermining the full potential of CCMT, as the technical solutions are perceived as merely avoiding efforts. If the resistance is indeed based on the fact that technological measures and investments are associated with the risk that sufficiency strategies should be avoided, i.e. are interpreted as an avoidance strategy, then a communication strategy that provides information about the impact relevance of these technologies while guided by appreciative communication regarding the necessity of sufficiency strategies, should be able to increase the acceptance of CCMT.

2.4 Research Questions and Research Aims

The overall research objective of the present study is the investigation of the effects of a strongly expressed restriction-oriented climate change mitigation heuristic (SER heuristic) on people's attitudes towards and acceptance of CCMT such as CCU in contrast to people characterized by a strongly expressed optimization-oriented climate change mitigation heuristic (hereinafter referred to as SEO heuristic). We chose CCU because it is an innovative and highly effective technology which, at the time of data collection, was not as controversial as CCS in terms of potential risks (see 2.1 for details). Furthermore, we wanted to examine the effects of a scenario-based intervention approach on people's attitude towards and acceptance of CCU, especially referring to people characterized by a SER heuristic. The core aspect of this intervention is to not only provide information about the climate mitigation potential of this technology, but also to convey the necessity of sufficiency strategies in an appreciative manner in order to prevent mistrust that technological strategies are being used to avoid sufficiency measures.

With regard to the initial findings from Matthies et al. (2023), the following (baseline-) hypotheses were tested[1]:

H0a: People characterized by a SER heuristic (hereinafter referred to as SER heuristic-people) report significantly lower supportive attitudes towards CCU than people characterized by a SEO heuristic (hereinafter referred to as SEO heuristic-people).

H0b: SER heuristic-people report significantly lower acceptance of CCU than SEO heuristic-people.

We further formulated several research hypotheses with regards to the overall effects of a scenario-based intervention approach on SER heuristic-people's attitude and acceptance exclusively:

H1a: Presenting a scenario in which the combination of different climate protection strategies (i.e., sufficiency, efficiency and the use of negative emission technologies like CCU) leads to the achievement of national climate protection goals (hereinafter referred to as

[1]Please note: The terms used to describe the groups do not completely correspond with the pre-registration terms. The content is consistent.

baseline vignette) significantly increases SER heuristic-people's supportive attitude towards CCU.

H1b: Presenting the baseline vignette significantly increases SER heuristic-peoples' acceptance of CCU.

We also examined the effects of a slightly different/ slightly supplemented scenario-based intervention (supplemented by the additional appreciative emphasis on the importance of the sufficiency strategy; hereinafter referred to as supplementary vignette) on SER heuristic-people's attitude and acceptance exclusively. By doing so, we tested the following research hypotheses:

H2a: Presenting the supplementary vignette significantly increases SER heuristic-people's supportive attitude towards CCU compared to the presentation of the baseline vignette.

H2b: Presenting the supplementary vignette significantly increases SER heuristic-people's acceptance of CCU compared to the presentation of the baseline vignette.

Finally, we also examined the possible effects of the examined scenario-based intervention approach on SEO heuristic-people's attitude and acceptance of CCU. Thereby, the following hypothesis was tested:

H3: Referring exclusively to SEO heuristic-people, neither the baseline vignette, nor the supplementary vignette leads to significant changes in people's attitude towards CCU or acceptance of CCU.

All hypotheses and analyses were pre-registered unless stated otherwise.

3 Materials and Methods

3.1 Participants and Procedure

Data were assessed via an online survey developed with the SoSci-survey software.
At the beginning of the survey, participants were inquired on the overall inclusion-criteria for the study. We used the inclusion-criteria procedure to make sure that only people with a fundamentally clear tendency in their assessment of different sustainability strategies (SER vs. SEO heuristics) took part in the actual survey at all (see inclusion criterion procedure for details).

In order to make sure that all participants were familiar with CCU, the inclusion-criteria procedure was followed by the presentation of a short video providing general information about CCU (see Appendix B for details on the information provided in the video). The video-presentation was followed by the pre-measurement of the dependent variables (see below for details) and the measurement of participants' expression of a restriction vs. optimization heuristic, which we used as the central criterion for group formation (SER heuristic- vs. SEO heuristic people) in the data analysis.

Afterwards, participants were randomly assigned to the two different vignette-based intervention-conditions and received a video-based vignette intervention (baseline vignette vs. supplementary vignette). Finally, the post-measurement of the dependent variables was conducted, and the survey closed by measuring participants' sociodemographic features.

Creating a scenario-based intervention approach

The intervention was realized by experimental vignette methodology (EVM), supplementing the baseline vignette (video with information about CCU) with a second vignette providing a specific scenario. EVM attempts to present the participants with a scenario that is as realistic as possible. The participants should put themselves in the situation presented in order to make

a decision under the given contextual conditions (Maddux & Rogers, 1983). Vignettes have already been applied to different scientific fields after being introduced by Rossi et al. (1974).

Vignettes are not designed to create a realistic image of reality (Wallander, 2012) or to induce immersion, because the focus is not on whether the generated scenario corresponds to reality, but rather on whether the activation of thought and behavioral processes is comparable to real life (Schmidt et al. 2022). Some studies have indeed shown that participants behave similarly in hypothetical and real scenarios and make comparable decisions (e.g. Peabody et al., 2004; Shah et al., 2007; Veloski et al., 2005). Following Atzmüller and Steiner (2010), we developed the vignettes considering experimental aspects (which are mainly manipulated), controlled aspects and additional contextual aspects to enrich the scenario without affecting the dependent variable.

Two different video-based vignettes were realized. Vignette 1 (baseline vignette) depicted a future scenario in which the combination of different climate protection strategies (sufficiency and efficiency strategies as well as the use of technologies such as CCU) leads to the fulfillment of national climate protection targets. In addition to the information provided in the baseline vignette, vignette 2 (supplementary vignette) also included an explicit appreciation of the importance of sufficiency strategies at the end of the video.

Inclusion Criterion Procedure

As mentioned above, the survey started with an inclusion criterion procedure in order to make sure that only people with a fundamentally clear tendency in their assessment of different sustainability strategies (SER vs. SEO heuristics) took part in the survey at all. This procedure was highly important, since our study was explicitly focused on the examination of people characterized by a strongly expressed restriction heuristic (SER heuristic-people). Therefore, it was necessary to directly exclude all people from participating in the survey who generally did not want to deal with the meaning of the two strategies in more detail and/or did not express a clear preference for one the two strategies.

Within the inclusion criterion procedure, we initially presented a short introduction-text on two different strategies for the achievement of national climate-protection goals in Germany (SER vs. SEO heuristics) to make sure that all participants were familiar with the general features of both climate-protection strategies:

"Please read the following information text on the implementation of Germany's national climate protection targets at your leisure and then answer the corresponding question:
Germany's national climate protection targets can be achieved through various types of climate protection measures. Sufficiency measures effectively reduce greenhouse gas emissions by enabling citizens to increasingly align their consumption patterns in terms of food, mobility and all other areas of daily life with climate-friendly consumption. Efficiency measures, on the other hand, reduce greenhouse gas emissions through technical solutions, for example by increasing the energy efficiency of technical devices and industrial production processes and/or replacing fossil fuels with renewable energies."

The presentation of this short introduction-text was then followed by the inclusion criterion-question: *„In your opinion, which of the two climate protection measures presented (sufficiency measures or efficiency measures) is more important for the long-term achievement of Germany's national climate protection targets? Please think carefully about which of the two measures seems more important to you and try to decide in favor of one of the two measures.*" When answering the inclusion criterion-question, participants' could choose between the following options: "sufficiency measures", "efficiency measures", "unfortunately, I can't decide - both types of measures are equally important" and "no

answer". Only participants, who chose the "sufficiency measures"- or the "efficiency measures"-option were then forwarded to the actual survey[2].

Exclusion Criterion and Final Sample

Data for the present study were collected across Germany from 13 – 27/09/2023 via an online survey. We followed the APA guidelines on the ethical conduct of research. According to German law, the present study did not require ethical approval for our survey as anonymity of the data was ensured, no sensitive data were assessed, and no experimental interventions were carried out. Participant acquisition and data collection was carried out by the panel provider company Bilendi, which ensured that all participants are at least 18 years old and German residents.

As we aimed to examine a special target group in this study (in particular people characterized by a strongly expressed restriction heuristic (SER heuristic-people), as well as people characterized by a strongly expressed optimization heuristic (SEO heuristic-people) in comparison), a comparatively comprehensive procedure to exclude unsuitable participants was necessary to form the final sample.

We excluded participants based on the inclusion criterion procedure (see above) at the beginning of our survey. Following the inclusion criterion procedure, N = 1081 participants were forwarded to the survey. Out of these, we excluded all participants who did not complete the whole survey and/ or gave a wrong answer to an attention check question referring to the CCU-information video (see Appendix B for details), resulting in a sample size of N = 418. After deleting all cases which spent too little time on the whole survey (i.e., less time spent than the mean time - 1.5x standard deviations), the sample was reduced to N = 401. Deviating from the pre-registration, we then implemented the final exclusion procedure by considering participants' values in the holistic[3] measure representing participants' expressed restriction heuristic (see Section 3.2 for details). The holistic measure could be calculated for N = 392 participants (M = 0.11, SD = 0.83, Min = -3.00, Max = 3.00). Since our study was focused on people who are characterized by a strongly/ expressed restriction/ optimization heuristic (not by a medium expressed restriction/ optimization heuristic), participants with values in the medium range of our holistic measure (i.e., values greater than or equal to -.50 and smaller or equal .50) were finally excluded from the sample. Based on this exclusion-criterion, our final sample was formed with N = 176 (with $N_{\text{SER heuristic}}$ = 100 and $N_{\text{WER heuristic}}$ = 76).

Table 1

3.2 Measures

In order to measure participants' supportive attitude towards CCU as well as their acceptance of CCU, we used several scales/ items (see Appendix A) which were already used in preliminary studies, to ensure the basic quality/suitability of the items (Matthies et al., 2023).

[2] Within the inclusion criterion procedure, we have further used a stratification-procedure resulting in a 50:50% ratio between participants, who chose the sufficiency- vs. the efficiency-measure.

[3] Difference-value for each participant from both scales (restriction heuristic – optimization heuristic), representing a holistic measure for participants' expressed restriction heuristic.

Supportive Attitudes towards CCU

To measure participants' attitude towards CCU, we asked them „*What is your attitude towards Carbon Capture and Utilization (CCU; CO_2 capture and subsequent use of carbon, e.g. bioplastics as a building material) as a technology to limit climate change?*" with answering-options ranging from (1) "very much against it" to (5) "very much in favor". Furthermore, we asked for participants' agreement referring to the following statement „*How much do you agree with the following statements about Carbon Capture and Utilization [...] as a technology to limit climate change? I support Carbon Capture and Utilization*." With answering-options ranging from (1) "strongly disagree" to (5) "strongly agree". Referring to both questions, participants' answers were measured referring to CCU in general, as well as specifically referring to the use of CCU for the medium-term storage of emissions (from the production of plastics) and for the long-term storage of emissions (from the production of building materials). Thus, altogether, we used 6 items to measure participants' attitude towards CCU, aggregated into an overall attitude-scale characterized by very high reliability in the pre- ($\alpha = .92$) as well as in the post-measurement ($\alpha = .92$).

Acceptance of CCU

To measure participants' acceptance of CCU, we asked for their agreement referring to the following statement „*How much do you agree with the following statement about Carbon Capture and Utilization [...] as a technology to limit climate change? I try to convince others of the importance of Carbon Capture and Utilization*" with answering-options on a Likert scale ranging from (1) "strongly disagree" to (5) "strongly agree". Again, we measured participants' agreement to this statement referring to CCU in general, as well as specifically referring to the use of CCU for the medium-term storage of emissions (from the production of plastics) and for the long-term storage of emissions (from the production of building materials). Against this background, we integrated three items into an overall acceptance-scale characterized by very high reliability in the pre- ($\alpha = .93$) as well as in the post-measurement ($\alpha = .92$).

Independent Variables: Expressed Restriction Heuristic and Expressed Optimization Heuristic

In order to measure participants' strongly expressed restriction/ optimization heuristic, we used scales/ items from prior research: Analogous to the measurement procedure from Matthies et al. (2023), we measured participants' expressed restriction heuristic with a scale consisting of five items (e.g., „*How much do you agree with the following statement? We have asked far too much of our planet in recent years, so now we have to pay the price and do without.*"; (1) "strongly disagree" to (5) "strongly agree"), characterized by very high reliability ($\alpha = .94$).

Furthermore, we measured participants' expressed optimization heuristic with a scale consisting of four items (e.g., „*How much do you agree with the following statement? As citizens of an industrialized nation, we can contribute to solving the global climate crisis primarily through investment.*"; (1) "strongly disagree" to (5) "strongly agree"), which showed acceptable reliability ($\alpha = .73$).

Within data analysis and in line with Matthies et al. (2023), we calculated a difference-value for each participant from both scales (restriction heuristic – optimization heuristic), representing a holistic measure for participants' expressed restriction heuristic (with positive values representing a more dominant restriction heuristic, while negative values represented a more dominant optimization heuristic).

4 Results

Statistical analyses were computed with the Statistical Package for the IBM SPSS Statistics 28 (IBM Cooperation 2020).

4.1 Differences in attitude towards and acceptance of CCU between SER vs. SEO heuristic participants

We examined possible differences in the dependent variables (pre-measurement) between SER and SEO heuristic participants by computing a MANOVA with both dependent variables (attitude towards CCU and acceptance of CCU) and group assignment (SER vs. SEO heuristic participants) as the independent variable. The data analysis revealed a significant overall effect ($F_{(2)} = 12.632$, $p < .001$; $\eta_p^2 = .15$). As summarized in Table 2, SER heuristic participants (attitude: $M_{SER} = 3.74$, $SD_{SER} = 1.02$; acceptance: $M_{SER} = 2.59$, $SD_{SER} = 1.29$) were characterized by lower values on both dependent variables than SEO heuristic participants were (attitude: $M_{SEO} = 4.27$, $SD_{SEO} = 0.69$; acceptance: $M_{SEO} = 3.58$, $SD_{SEO} = 1.09$). Against this background, our baseline hypotheses (H0a and H0b) were clearly confirmed by the data.

Table 2

4.2 Overall effect of a scenario-based intervention approach on SER heuristic-people's supportive attitude and acceptance

To examine the overall effect of our scenario-based intervention approach on SER heuristic-participants' attitude towards CCU and on their acceptance of CCU, we computed a repeated-measurement ANOVA for both dependent variables. In line with our research hypotheses H1a and H1b, the analyses identified a significant increase for SER heuristic-participants supportive attitude towards CCU ($F_{(1)} = 5.492$, $p < .01$; $\eta_p^2 = .05$; $M_{SER\text{-}pre} = 3.79$, $SD_{SER\text{-}pre} = 0.98$; $M_{SER\text{-}post} = 3.90$, $SD_{SER\text{-}post} = 0.95$), as well as a highly significant increase of their acceptance of CCU ($F_{(1)} = 14.505$, $p < .001$; $\eta_p^2 = .14$; $M_{SER\text{-}pre} = 2.60$, $SD_{SER\text{-}pre} = 1.30$; $M_{SER\text{-}post} = 3.00$, $SD_{SER\text{-}post} = 1.34$) from pre- to post-measurement (see Table 3 for an overview).

Table 3

4.3 Comparing effects in the dependent variables between baseline vignette-intervention vs. supplementary vignette-intervention

We examined possible differences in the effects of both types of vignette-interventions on SER heuristic participants attitude towards CCU and their acceptance of CCU by computing a repeated-measurement ANOVA for each dependent variable with vignette-intervention (baseline vs. supplementary) as the independent variable. A significant interaction effect between time of measurement and vignette-intervention could not be identified, neither for SER heuristic participants' attitude towards CCU ($F_{(1)} = 0.549$, $p = .46$), nor for their acceptance of CCU ($F_{(1)} = 0.128$, $p = .72$) (see Table 4 for all details). Thus, our research hypotheses H2a and H2b were not supported by the data.

Table 4

4.4 Examining vignette-intervention effects on SEO heuristic-people's supportive attitude and acceptance

To finally examine possible (or the expected absent) overall effect of our scenario-based intervention approach on SEO heuristic-participants' supportive attitude towards CCU and on their acceptance of CCU, we also computed a repeated-measurement ANOVA for both dependent variables in this specific group of participants. In contrast to the results of this analysis in the group of SER heuristic participants and, thus, in line with our expectations, no significant changes were identified in the analysis – neither for SEO heuristic participants' supportive attitude towards CCU ($F_{(1)} = 3.296$, $p = .07$, nor for their acceptance of CCU ($F_{(1)} = 2.221$, $p = .14$; see Table 5 for all details). Thus, our final research hypothesis H3 was confirmed by the data.

Table 5

5 Discussion

The overall research aim of our study was to examine the effects of a strongly expressed restriction-oriented climate change mitigation heuristic (SER heuristic) on people's supportive attitudes towards and acceptance of negative emission technologies (CCMT) such as Carbon Capture and Utilization (CCU): In line with initial findings from previous research (Matthies et al., 2023) our study provides further empirical evidence for such effects by showing SER heuristic-people reporting significantly lower supportive attitudes towards CCU as well as significantly lower acceptance of CCU than people characterized by a strongly expressed optimization-oriented climate change mitigation heuristic (SEO heuristic-people).

In addition to this examination of SER heuristic's consequences on people's attitude towards and acceptance of CCU, we further investigated the effects of a scenario-based intervention approach on people's attitude and acceptance – especially referring to SER heuristic-people: By doing so, we presented a scenario in which the combination of different climate protection strategies (i.e., sufficiency, efficiency and the use of CCMT like CCU) leads to the achievement of national climate protection goals.

The main function of our scenario-based intervention was to convey the necessity of sufficiency strategies in an integrative and thus highly effective national climate-protection program in an appreciative manner. The mistrust that technological strategies are used to avoid sufficiency measures should thus be prevented.

Our results imply our scenario-based intervention approach to be an effective tool for the promotion of SER heuristic-people's supportive attitude towards CCU as well as for their acceptance of CCU. In contrast to our expectations, we found no empirical evidence for stronger intervention effects, when presenting a slightly supplemented scenario-based intervention (supplemented by the additional appreciative emphasis on the importance of the sufficiency strategy).

Finally, our results imply the examined scenario-based intervention approach to be effective for the promotion of SER heuristic-people's supportive attitude towards and acceptance of CCU, while no intervention effects were found for SEO heuristic-people. From an application perspective, the lack of an intervention effect for the SEO heurist-people is positive: the scenario-based intervention (combination of sufficiency and efficiency strategies) apparently

did not lead to reactance among the SEO heuristic-people, making this communication strategy a feasible broad communication strategy.

The aim of this study was to test the effect of an intervention that aims to increase the acceptance of CCU[4] for people with a strongly restriction-oriented heuristic. In this study, the strongly restriction-oriented heuristic was contrasted with an optimization heuristic, whereby these heuristics are not designed as opposites. These efforts are based on initial empirical findings that a very strong restriction heuristic can hinder the acceptance of innovative, highly effective technologies for mitigating climate change. The study at hand was able to show that providing easily accessible information about CCU technology in combination with a generally support of the concept of sufficiency could lead to an increase in the supportive attitude towards and acceptance of CCU.

It is quite likely that the narrative of technical solutions triggers the concern among people with strong restriction heuristics that the (political) promotion of technical solutions goes hand in hand with an undermining of sufficiency strategies, i.e. that technical solutions are pursued in order to avoid sufficiency. If these urgently needed technologies to mitigate climate change are to be further supported, two key strategies must be pursued: firstly, transparent communication about the opportunities, risks and impact of the technologies, and secondly, communication that addresses the importance of sufficiency strategies in order to dispel concerns. Due to the urgency of the situation, all resources must be pooled in order to drive climate change mitigation forward. It can therefore no longer be a question of "either or".

Limitations and further research

The sample was restricted to the German population. The findings presented and discussed here should therefore be considered embedded in their national context. In this context, it should be noted that the environmental movement in Germany in particular tends to be skeptical of technology, especially when it comes to large-scale plants. We therefore recommend that future studies also measure general affinity or skepticism towards technology. However, we assume that the relevance of the described heuristics and the impact of the tested intervention to transform a strong restriction heuristic into the direction of an optimization heuristic might be of relevance for other countries as well. Furthermore, the representativeness was further limited by the strict selection criteria in relation to the heuristics. However, the restriction of the sample was absolutely necessary in order to be able to realize the experimental design properly. At the same time, the strong sample reduction indicates that the proportion of people with very dominant heuristics in the population is probably not particularly large. However, as no reactance effects were found for the SEO heuristic participants, this does not represent a significant risk for the communication strategy proposed here.

Due to this strict selection criteria and the associated sample reduction, a simple experimental design was chosen for this study. Although the effect of the intervention could be demonstrated by the pre-post-test, an additional control group would be recommended for future studies, which would allow the isolated effect of information provision to be tested without any reference to sufficiency strategies.

In our view, the present findings already provide helpful indications for future target-oriented communication of necessary CCMT. However, even if the findings confirm the use of the underlying heuristics, it seems promising to analyze the structures of these heuristics

[4] The CCU technology was selected as a substitute for innovative technologies to mitigate climate change.

even more in-depth, especially with regard to conflict potentials.

6 Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

7 Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

8 Authors' contributions

KS, AB, EM and FK contributed to the conception and design of the study. KS and AB contributed to the analysis strategies and interpretation of data. KS organized the database and performed the statistical analyses. FK designed the videos and contributed to the development of the vignettes. AB and KS wrote the first draft of the manuscript. MB, JA and wrote sections of the manuscript. EM supervised the project. All authors provided critical feedback and helped shape the manuscript.

9 Funding

The study was conducted in the frame of the interdisciplinary research initiative "SmartProSys: Intelligent Process Systems for the Sustainable Production of Chemicals". The research was funded by the Federal State of Saxony-Anhalt, Ministry for Science, Energy, Climate Protection and the Environment.

10 Conflicts of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as potential conflicts of interest.

11 References

Atzmüller, C., and Steiner, P. M. (2010). Experimental Vignette Studies in survey research. *Methodology* 6, 128–138. doi.org/10.1027/1614-2241/a000014.

Bamberg, S., Hunecke, M., and Blöbaum, A. (2007). Social context, personal norms and the use of public transportation: Two field studies. *Journal of Environmental Psychology* 27, 190–203. doi: 10.1016/j.jenvp.2007.04.001.

Barclay, L.J., Skarlicki, D.P., and Pugh, S.D. (2015). Exploring the role of emotions in injustice perceptions and retaliation. *Journal of Applied Psychology* 90, 629.

Baum, C.M., Fritz, L., Low, S., and Sovacool, B.K. (2024). Public perceptions and support of climate intervention technologies across the Global North and Global South. *Nat Commun* 15, 2060. doi.org/10.1038/s41467-024-46341-5.

BDI, DGB, NABU, & WWF. (2024, 01-10-2024). *Industrietransformation aus einem Guss.* https://www.nabu.de/imperia/md/content/nabude/sustainablefinance/240110-nabu-industrie-gemeinsames-thesenpapier.pdf

Böcher, M., Töller, A. E., Perbandt, D., Beer, K., and Vogelpohl, T. (2020). Research trends: Bioeconomy politics and governance. *Forest Policy and Economics* 118, 102219. doi.org/https://doi.org/10.1016/j.forpol.2020.102219.

Brundtland, G.H. (1987). *Our Common Future: Report of the World Commission on Environment and Development*.Geneva: Oxford University Press.

Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz (BMUV) and Umweltbundesamt (UBA) (2023): *Umweltbewusstsein in Deutschland 2022.* Ergebnisse einer repräsentativen Bevölkerungsumfrage, Umweltbundesamt, Berlin, Dessau-Roßlau. https://www.umweltbundesamt.de/publikationen/umweltbewusstsein-in-deutschland-2022

European Commission. (2023). *Special Eurobarometer SP 538: Climate Change*. https://commission.europa.eu/about-european-commission/departments-and-executive-agencies/communication.

Fritsche, I., Barth, M., Jugert, P., Masson, T., and Reese, G. (2018). A social identity model of proenvironmental action (SIMPEA). *Psychological Review* 125, 245–269. doi: 10.1037/rev0000090.

Gigerenzer G (2015) *Simply rational: decision making in the real world.* New York: Oxford University Press. doi.org/10.1093/acprof:oso/9780199390076.001.0001.

Gigerenzer, G. (2008). Why heuristics work. *Perspectives on Psychological Science* 3, 20–29.

Gigerenzer, G., and Gaissmaier, W. (2011). Heuristic decision making. *Annual Review of Psychology* 62, 451–482.

Greenpeace. (2024). *CCS: Breites Umweltbündnis warnt vor gefährlichem Irrweg* https://www.greenpeace.de/publikationen/Pressemitteilung_CCS.pdf.

Hjeij, M. and Vilks, A. (2023). A brief history of heuristics: how did research on heuristics evolve? *Humanities and Social Science Communications* 10, 64. doi.org/10.1057/s41599-023-01542-z.

IBM Corporation. (2022). *IBM SPSS Statistics for Windows* (Version 28.0).

IPCC. (2018). Annex 1: „Glossary“, in *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*, ed. J. B. R. Matthews (Cambridge: University Press), 541-562. doi.org/10.1017/9781009157940.008

IPCC (2022). *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, UK and New York, NY, USA. doi.org/10.1017/9781009157926.

IPCC. (2023). *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, ed. H. Lee and J. Romero (IPCC, Geneva, Switzerland), 35-115. doi:10.59327/IPCC/AR6-9789291691647.

Kahneman, D. (2011). *Thinking fast and slow.* New York: Farrar, Straus and Giroux.

Klöckner, C.A. (2013). A Comprehensive Model of the Psychology of Environmental Behaviour – A Meta-Analysis. *Global Environmental Change* 23, 1028-1038. doi:10.1016/j.gloenvcha.2013.05.014.

Korteling, J.E.H., Paradies, G.L., and Sassen van Meer, J.P. (2023). Cognitive bias and how to improve sustainable decision making. *Frontiers in Psychology* 14, 1–14.

Leung, D. Y., Caramanna, G., and Maroto-Valer, M. M. (2014). An overview of the current status of carbon dioxide capture and storage technologies. *Renewable and Sustainable Energy Reviews* 39, 426–443.

Maddux, J.E., and Rogers, R.W. (1983). Protection motivation and self-efficacy: A revised theory of fear appeals and attitude change. *Journal of Experimental Social Psychology* 19, 469–479. 10.1016/0022-1031(83)90023-9.

Matthies, E., de Paula Sieverding, T., Engel, L., and Blöbaum, A. (2023). Simple and Smart: Investigating Two Heuristics That Guide the Intention to Engage in Different Climate-Change-Mitigation Behaviors. *Sustainability* 15, 7156. doi.org/10.3390/su15097156.

Meadows, D.H., Meadows, D.L., Randers, J., and Behrens, W.W. (1972). *The Limits to Growth: A Report for the Club of Rome's Project on the Predicament of Mankind*. New York: Universe Books.

Messner, D., Schellnhuber, J., Rahmstorf, S., and Klingenfeld, D. (2010). The budget approach: A framework for a global transformation toward a low-carbon economy. *Journal of Renewable and Sustainable Energy* 2, 031003. doi.org/10.1063/1.3318695

Mol, A.P.J. (2000). The environmental movement in an era of ecological modernisation. *Geoforum* 31, 45-56.

Napp, T., Hills, T., Soltani, S.M., Bosch, J. and Mazur, C. (2017). *A survey of key technological innovations for the low-carbon economy.* Imperial College London, Grantham Institute.

Osman M. (2010). Controlling uncertainty: a review of human behavior in complex dynamic environments. *Psychological Bulletin* 136, 65-86. doi: 10.1037/a0017815. PMID: 20063926.

Peabody, J. W., Luck, J., Glassman, P., Jain, S., Hansen, J., Spell, M., and Lee, M. (2004). Measuring the quality of physician practice by using clinical vignettes: A prospective validation study. *Annals of Internal Medicine* 141, 771–780.

Perišić, M., Barceló, E., Dimic-Misic, K., Imani, M., and Spasojević Brkić, V. (2022). The role of bioeconomy in the future energy scenario: a state-of-the-art review. *Sustainability*, 14, 560. doi.org/10.3390/su14010560.

Rossi, P. H., Sampson, W. A., Bose, C. E., Jasso, G., and Passel, J. (1974). Measuring household social standing. *Social Science Research* 3, 169–190.

Santa, J.C., and Drews, S. (2023). Heuristic processing of green advertising: Review and policy implications. *Ecological Economics* 206, 107760.

Schmelzer, M. (2017). Born in the corridors of the OECD': the forgotten origins of the Club of Rome, transnational networks, and the 1970s in global history. *Journal of Global History* 12, 26–48. doi:10.1017/S1740022816000322.

Schmidt, K., Kösling, P., Bamberg, S., and Blöbaum, A. (2022). A Prospect Theory-based experimental vignette methodology for exploring rebound effects and rebound-damping interventions. *Ecological Economics* 193, 107302. doi.org/10.1016/j.ecolecon.2021.107302.

Shah, R., Edgar, D., and Evans, B. J. W. (2007). Measuring clinical practice. *Ophthalmic & Physiological Optics* 27, 113–125.

Simon, H.A. (1955). A behavioural model of rational choice. *The Quarterly Journal of Economics* 69, 99–118.

Steg, L., Bolderdijk, J. W., Keizer, K., and Perlaviciute, G. (2014). An Integrated Framework for Encouraging Pro-environmental Behaviour: The role of values, situational factors and goals. *Journal of Environmental Psychology* 38, 104–115. doi: 10.1016/j.jenvp.2014.01.002.

Stegmann, P., Londo, M., and Junginger, M. (2020). The circular bioeconomy: Its elements and role in European bioeconomy clusters. *Resources, Conservation & Recycling* X, 6, 100029. doi.org/10.1016/j.rcrx.2019.100029.

Stern, P. (2000). New Environmental Theories: Toward a Coherent Theory of Environmentally Significant Behavior. *Journal of Social Isssues* 56, 407–424. doi: 10.1111/0022-4537.00175.

Sunaryo, T., Radyati, M.R.N., Utha, M.A., Rinanti, A., and Minarti, A. (2023). Research Development on Carbon Capture, Utilization and Storage as a Climate Change Mitigation Technology. *Journal of Environmental Research, Engineering and Management* 79, 37–55. DOI 10.5755/j01.erem.79.1.32424.

Thøgersen, J. (2006). Norms for environmentally responsible behaviour: An extended taxonomy. *Journal of Environmental Psychology* 26, 247–261. doi: 10.1016/j.jenvp.2006.09.004.

Veloski, J., Tai, S., Evans, A. S., and Nash, D. B. (2005). Clinical vignette-based surveys: A tool for assessing physician practice variation. *American Journal of Medical Quality* 20, 151–157.

Wallander, L. (2012). Measuring social workers' judgements: Why and how to use the factorial survey approach in the study of professional judgements. *Journal of Social Work* 12, 364–384.

Wassmann, B., Siegrist, M., and Hartmann, C. (2023). The role of heuristics for composing an environmentally friendly meal. *Journal of Cleaner Production* 402, 136818.

Tables

Table 1

Sociodemographic feature	Sample
Gender	
Male	60.8%
Female	38.6%
Diverse	0.6%
Age	
M (SD)	47.62 (14.33)
Min	19
Max	69
Education	
Primary school not completed	1.1%
Primary school completed	6.3%
Secondary education	23.9%

Higher education entrance qualification	29.6%
University degree	38.6%
Household income per month	
Less than € 500	4.0%
€ 500 – less than € 1,000	5.1%
€ 1,000 – less than € 1,250	4.5%
€ 1,250 – less than € 1,500	6.3%
€ 1,500 – less than € 2,000	5.7%
€ 2,000 – less than € 2,500	13.1%
€ 2,500 – less than € 3,000	14.2%
€ 3,000 – less than € 3,500	6.3%
€ 3,500 – less than € 4,000	10.8%
€ 4,000 – less than € 5,000	17.6%
More than € 5,000	12.5%

Table 2

Differences in supportive attitude towards CCU and acceptance of CCU (pre-measurement) between SEO vs. SER heuristic participants.

Dependent Variable	Group	N	M (SD)	F	p	η_p^2
Supportive Attitude towards CCU	SEO	59	4.27 (0.69)	12.362	<.001***	.08
	SER	90	3.74 (1.02)			
Acceptance of CCU	SEO	59	3.58 (1.09)	23.672	<.001***	.14
	SER	90	2.59 (1.29)			

Note. SEO = participants characterized by a strongly expressed optimization heuristic; SER = participants characterized by a strongly expressed restriction heuristic

**p < .05; **p < .01; **p < .001*

Table 3

Differences in attitude towards CCU and acceptance of CCU of SER heuristic participants between pre- and post-measurement.

Dependent Variable	Measurement	N	M (SD)	F	p	η_p^2
Attitude towards CCU	pre	100	3.79 (0.98)	5.492	.02*	.05
	post		3.90 (0.95)			
Acceptance of CCU	pre	88	2.60 (1.30)	14.505	<.001***	.14
	post		3.00 (1.34)			

*Note. *p < .05; **p < .01; ***p < .001*

Table 4

Differences in changes in attitude towards CCU and acceptance of CCU in SER heuristic participants depending on vignette-intervention.

Dependent Variable	Vignette-intervention	Measurement	N	M (SD)	F	p	η_p^2
Attitude towards CCU	x_1	pre	48	3.87 (0.86)	0.549	.46	--
		post		3.94 (0.83)			
	x_2	pre	52	3.72 (1.07)			
		post		3.87 (1.06)			
Acceptance of CCU	x_1	pre	41	2.41 (1.28)	0.128	.72	--
		post		2.81 (1.24)			
	x_2	pre	47	2.76 (1.31)			
		post		3.09 (1.43)			

Note. x_1 *= basic vignette-intervention,* x_2 *= supplementary vignette-intervention;*
**p < .05; **p < .01; **p < .001*

Table 5

Differences in supportive attitude towards CCU and acceptance of CCU of SEO heuristic participants between pre- and post-measurement.

Dependent Variable	Measurement	N	M (SD)	F	p	η_p^2
Supportive attitude towards CCU	pre	65	4.27 (0.69)	3.296	.07	--
	post		4.34 (0.72)			
Acceptance of CCU	pre	59	3.58 (1.09)	2.221	.14	--
	post		3.73 (1.24)			

*Note: *p < .05; **p < .01; **p < .001*

Appendix

Table A.1.

Scales/ items used in the study and descriptive statistics.

Scale/ items	Number of items	Formulation	Reply options	Reliability	M (SD)	Min	Max
Attitudes towards CCU	6	What is your attitude towards Carbon Capture and Utilization (CCU; CO2 capture and subsequent use of carbon, e.g. bioplastics as a building material) as a technology to limit climate change? • referring to CCU in general • referring to the use of CCU for the medium-term storage of emissions (from the production of plastics) • referring to the use of CCU and for the long-term storage of emissions (from the production of building materials)	(1) "very much against it" - (5) "very much in favor"	α = .92 (pre) α = .92 (post)	pre: 3.98 (0.90) post: 4.09 (0.89)	1	5
		How much do you agree with the following statements about Carbon Capture and Utilization (CCU; CO2 capture and subsequent use of carbon, e.g. bioplastics as a building material) as a technology to limit climate change? I support Carbon Capture and Utilization." • referring to CCU in general • referring to the use of CCU for the medium-term storage of emissions (from the production of plastics)	(1) "strongly disagree" - (5) "strongly agree"				

		• referring to the use of CCU and for the long-term storage of emissions (from the production of building materials)			
Acceptance of CCU	3	How much do you agree with the following statements about Carbon Capture and Utilization (CCU; CO2 capture and subsequent use of carbon, e.g. bioplastics as a building material) as a technology to limit climate change? I try to convince others of the importance of Carbon Capture and Utilization. • referring to CCU in general • referring to the use of CCU for the medium-term storage of emissions (from the production of plastics) • referring to the use of CCU and for the long-term storage of emissions (from the production of building materials)	(1) "strongly disagree" - (5) "strongly agree"	α = .93 (pre) α = .92 (post)	pre: 2.96 (1.32) post: 3.29 (1.34)
Expressed Restriction Heuristic	5	How much do you agree with the following statement? • We have asked far too much of our planet in recent years, so now we have to pay the price and do without. • We cannot buy our way out of the climate crisis. • We in the western industrialized nations are to blame for the climate crisis and must now bear the consequences. • Restrictions on climate protection are the just punishment for our overconsumption.	(1) "strongly disagree" - (5) "strongly agree"	α = .94	3.48 (1.19)

		• The Western lifestyle is the cause of climate change, and it is only fair that we are now affected by severe restrictions.					
Expressed Optimization Heuristic	4	How much do you agree with the following statement? • As citizens of an industrialized nation, we can contribute to solving the global climate crisis primarily through investment. • In order to limit the climate crisis quickly, each individual should implement measures in their own area that save a particularly large amount of CO_2. • I am prepared to invest money to limit the climate crisis. • Everyone should know their carbon footprint so that they can start where it makes the most difference.	(1) "strongly disagree" - (5) "strongly agree"	α = .73	3.22 (0.96)		
Attention check	1	Please briefly answer the following question about the Carbon Capture and Utilization (CCU): In which products can **NO** CO_2 be stored using CCU?	In food; In fuels; In building materials; In plastics; I do not know. [(a)]	--	--	--	--

Note: M = mean value; SD = standard deviation; Min = Minimum; Max = Maximum. [(a)] participants, who gave a wrong answer ("in food" or "I do not know") to this attention check question were excluded.

Appendix B

B.1: Script used for the video short video providing general information about CCU:

In order to achieve the Paris climate targets and the associated 1.5-degree target, emissions on earth need to be drastically reduced. Our current greenhouse gas emissions take on proportions that we simply cannot compensate for in the long run.

To counteract this, carbon must be extracted from the atmosphere in the short and long term. One technology that temporarily stores CO_2 in other products is CCU: carbon capture and utilization. With this technology, CO_2 is either extracted directly from the air or from combustion exhaust gasses, stored, and subsequently transformed into one of many possible products. The wide range of possible products spans from base chemicals such as methanol, to fuels, plastics (for example mattresses or car interiors) and construction materials. The longer the lifespan of the product, the better its climate balance: a long product lifespan ensures that carbon is kept out of the atmosphere for a longer period of time. Fuels produced with CCU therefore only have a very limited carbon storage effect, as they quickly return CO_2 to the atmosphere. Plastics can store carbon for around 10 to 20 years, depending on the product. Construction materials can withdraw and store carbon from the atmosphere for up to 100 years.

B.2: Script used for the video-based vignette 1 (basic vignette):

The year is 2060. As planned, Germany's national climate protection goals were successfully implemented through various climate protection strategies in politics, industry, and society. Citizens increasingly adjusted their consumption patterns regarding diet, mobility, and all other areas of daily life to achieve more sufficient, climate-friendly consumption behaviors. At the same time, the CO_2 emissions of all industrial processes and technologies were increasingly optimized and the remaining climate-damaging emissions compensated through the use of negative emissions technologies such as CCU.

Thereby, CCU is predominantly used for the production of long-lasting carbon-storage products such as construction materials. Short-term carbon-storage products such as fuels are rarely produced using CCU, and only to guarantee a safety net of necessary infrastructure like emergency power generators for hospitals.

B.3: Script used for the video-based vignette 2 (supplementary vignette):

The year is 2060. As planned, Germany's national climate protection goals were successfully implemented through various climate protection strategies in politics, industry, and society. Citizens increasingly adjusted their consumption patterns regarding diet, mobility, and all other areas of daily life to achieve more sufficient, climate-friendly consumption behaviors. At the same time, the CO_2 emissions of all industrial processes and technologies were increasingly optimized and the remaining climate-damaging emissions compensated through the use of negative emissions technologies such as CCU.

Thereby, CCU is predominantly used for the production of long-lasting carbon-storage products such as construction materials. Short-term carbon-storage products such as fuels

are rarely produced with CCU, and only to guarantee a safety net of necessary infrastructure like emergency power generators for hospitals.

Politics, industry and society agree, that the climate protection goals were only successfully met due to the combination of these different strategies. The promotion of sufficient lifestyles continues to be regarded as the most important factor for climate protection.