Information on public opinion has lasting effects on second-order climate beliefs, but minimal and ephemeral effects on first-order beliefs

Matthew Barnfield [a,*] [ID], Paula Szewach [b], Sabrina Stöckli [c], Florian Stoeckel [d], Jack Thompson [e], Joseph Phillips [f], Benjamin Lyons [g], Vittorio Mérola [h], Jason Reifler [i]

[a] School of Politics and International Relations, Queen Mary University of London, United Kingdom
[b] Barcelona Supercomputing Center, Spain
[c] Department of Consumer Behavior, University of Bern, Switzerland
[d] Department of Politics, University of Exeter, United Kingdom
[e] Centre for Decision Research, University of Leeds, United Kingdom
[f] School of Law and Politics, Cardiff University, United Kingdom
[g] Department of Communication, University of Utah, USA
[h] School of Government and International Affairs, Durham University, United Kingdom
[i] Department of Politics and International Relations, University of Southampton, United Kingdom

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ABSTRACT

Across western democracies, pro-climate beliefs are widespread. Yet, vocal minorities contest scientific consensus about global warming. Perhaps as a consequence, the extent to which the public accepts global warming and climate action is often underestimated. Correcting this perceptual deficit has been proposed as a promising way to strengthen climate action, since knowledge of broad public consensus could motivate environmentally friendly behaviours, increase support for policy interventions, or shift perceptions of political feasibility. In a preregistered two-wave survey experiment in Germany, we provide a novel test of this strategy in a national context with already high pro-climate support, using real and comprehensive public opinion data. We find that exposure to this information can produce a lasting, significant increase in second-order beliefs (perceptions of public opinion) two weeks after treatment, especially among those who initially underestimated public support. However, the effects on first-order outcomes—policy feasibility perceptions, attitudes, and behavioural intentions—are small, short-lived, and largely non-significant. By demonstrating the boundary conditions of second-order interventions, our study suggests that their promise may be more limited than often assumed. These findings may highlight the potential need for more targeted, repeated, and context-sensitive approaches if second-order information is to meaningfully shift climate beliefs and behaviours.

1. Introduction

Belief in climate change and support for policies to mitigate it are widespread (Andre et al., 2024; Ballew et al., 2019; Eurobarometer, 2021). But there is growing evidence that citizens in the USA (Mildenberger & Tingley, 2019; Sokoloski et al., 2018; Sparkman & Walton, 2017), China (Ji et al., 2025; Mildenberger & Tingley, 2019), Spain (Drews et al., 2022), Australia (Leviston et al., 2013), and around the whole world (Andre et al., 2024), significantly underestimate the level of public belief in climate change and support for environmental policy interventions.

Scholars propose that such underestimation of public support may present a significant barrier to climate action (Mildenberger & Tingley, 2019; Ballew et al., 2020; Goldberg, van der Linden, et al., 2020), and that correcting this tendency would increase pro-climate behaviours and beliefs (Abeles et al., 2019; Ballew et al., 2019). Since 'beliefs about other people's opinions on climate change influence one's own opinion' (Drews et al., 2022), it is argued that 'raising awareness about the broad global support for climate action becomes critically important in promoting a unified response to climate change' (Andre et al., 2024). In other words, correcting people's *second-order* beliefs (about the beliefs of others) could positively influence their own *first-order* attitudes and behaviours, producing positive climate outcomes.

Drawing on Miller and Prentice (2016), there are at least three

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plausible mechanisms through which these effects could operate. First, second-order information about how widespread pro-climate views are could "liberate" would-be pro-climate actors. Short of actually changing people's underlying convictions or preferences about climate change, information about how widespread those views are could simply alleviate perceived social pressure, liberating people to more openly express and act on those preferences. Indeed, Geiger and Swim (2016) found that psychology undergraduates in the US were more willing to discuss climate change with their peers when led to believe that those peers shared their beliefs. This finding suggests that increasing second-order beliefs about the number of people holding pro-climate views increased people's comfort with expressing those pro-climate views, in line with the theory of the "spiral of silence" (Noelle-Neumann, 1974). Plausibly, if people are more willing to express their pro-climate beliefs when they feel those views are shared, they will also be more willing to act on them: 'by showing them that their preference is widely shared, the restraining force that has kept these individuals from acting on their preference is removed, and their behaviour will fall in line with their preference' (Miller & Prentice, 2016, p. 355; see also Ji et al., 2025).

Secondly, second-order information could drive people to act on first-order pro-climate beliefs by convincing them that it is worth bothering to do so—that is, by informing a sense of *efficacy* (Miller & Prentice, 2016, see also Bolsen et al., 2014). The benefits of climate action are "group-contingent"—it only works if actions are widely taken (Mildenberger & Tingley, 2019). Therefore, people may be more willing to take action when they perceive public opinion passing a sufficient "tipping point" threshold (Andrighetto & Vriens, 2022). Jachimowicz et al. (2018) have shown, indeed, that people are more likely to adopt energy savings measures when told that many others in their local area are doing so. Taking this logic further, citizens might be more willing to adopt measures to reduce their carbon footprint—flying less, using public transport, using greener energy sources—if they believe pro-climate opinion to be widespread, and therefore see it as more likely that lots of other people will engage in these behaviours too, producing a significant aggregate impact. Indeed, Bolsen et al. (2014, p. 66) find the inverse: that telling American respondents (falsely) that only a small *minority* of Americans believe climate change is caused by humans and would consider 'driving smaller cars, reducing travel, and supporting legislation (e.g., a tax) to reduce the nation's emission of greenhouse gases' significantly *reduces* their perceptions of efficacy and willingness to take action.

As this finding suggests, the same mechanism could engender support for pro-climate policy, as well as fostering individual uptake of environmentally friendly behaviours (Ballew et al., 2020; Goldberg, van der Linden, et al., 2020). Underestimating pro-climate opinion may lead citizens to erroneously perceive these policies as unfeasible, and reduce their support accordingly. Suggestively, Mildenberger and Tingley (2019) have recently shown that US citizens display increased support for the US signing the US-China Climate Accord when they learn that 98 % of the Chinese population believes that 'global warming is happening'. An obvious reason for this finding may be that they treat the Chinese public's widespread belief in climate change as a signal that they will support the Accord.

Indeed, if this mechanism is in operation, we would not only expect correcting people's second-order beliefs about climate change to influence their support for climate policies, but also their perceptions of how likely those policies are to be adopted. Two different logics could underpin this association: *responsiveness* or *selection* (Tomz et al., 2020). Under responsiveness, public opinion drives policy adoption directly by inducing existing government officials to pursue popular policies. Under selection, public opinion drives policy adoption through the public electing likeminded candidates and parties. Second-order opinions can influence how much citizens expect their governments to follow through on pro-climate policy, either through the pressure they expect to be applied to existing officials or in how they expect future electorates to vote in elections.

Thirdly, as well as affecting how willing people are to express or act in line with their climate change beliefs, second-order information might actually cause people to update those beliefs directly, through what Miller and Prentice (2016) refer to as "corroboration". Per their example, 'those who learn that they consume more energy than their neighbors can reasonably assume that their neighbors find the pro-environmental case to be persuasive' (Miller & Prentice, 2016, p. 355). More broadly then, learning that the public buys into the scientific consensus that significant global warming is caused by human activity and must be addressed with (radical) action may serve to corroborate that consensus in the eyes of someone who is otherwise sceptical, leading them to update their first-order beliefs about climate change, and thereby possibly altering their behaviour. Work by Van Der Linden (2015), indeed, finds that messaging about the environmental cost of using plastic water bottles only persuades students to reduce their bottled water consumption when combined with messaging about how the majority of their peers are reducing theirs, implying that individuals' acceptance of pro-climate arguments might rely on their peers' acceptance of those arguments.

In broad outline then, there is theoretical support for the possibility that second-order information about public consensus on climate change could affect the following individual-level first-order climate outcomes: belief in the existence of climate change caused by human activities, intention to adopt environmentally friendly behaviours, support for policies to mitigate global warming, and belief in the political feasibility of those policies.

However, despite this theoretical support, there are also empirical and methodological reasons to doubt how effective second-order interventions will be in producing such first-order outcomes. For one thing, though suggestive, the evidence discussed above in support of these theoretical mechanisms rarely directly or straightforwardly demonstrates that, in general, correcting people's underestimation of public pro-climate belief will positively affect a range of their own attitudes and behaviours. For example, although Bolsen et al. (2014) find that they can *reduce* people's intention to adopt environmentally friendly behaviours by telling them that a minority of the public would consider adopting those behaviours, they find 'frequently null effects' when trying to *increase* those behaviours by telling people the majority would consider adopting them. Recent evidence also suggests that information about levels of support for a carbon tax has little effect on acceptance of that tax in Spain (Drews et al., 2022). Research on the "Gateway Belief Model" suggests that very large shifts in perceptions of scientific consensus on climate change may be required to produce very small changes in first-order beliefs (Van der Linden et al., 2019). The same may well apply to perceptions of *public* consensus. Other major findings in the literature are very nuanced, shedding valuable light on very specific cases that nonetheless might not be generalizable to the broader strategy of adopting second-order communication in climate policy (e.g. Jachimowicz et al., 2018; Mildenberger & Tingley, 2019). Some experimental studies also opt to misinform people about public consensus (e.g. Bolsen et al., 2014; Geiger & Swim, 2016)—an approach that not only raises important ethical questions but also could not feasibly be adopted in real-world political communications (see Barnfield, 2023). And of course, even if shifting perceptions of second-order opinion does shift first-order opinions and behaviours in the short-term, there is no guarantee that they sustain in the long-term (Goldberg, Gustafson, & Van Der Linden, 2020). The effect of a second-order communication may simply decay over time, or may also be overridden by significant political events that more strongly shift perceptions and preferences. Corrections of factual misperceptions often work in the short run, but these seem to fade quickly (Carey et al., 2022). Accordingly, a recent meta-analysis tends to find the effects of attitudinal interventions are short-lived (Nisa et al., 2019). Indeed, often such interventions, even when highly impactful on public understanding, have immediate effects on climate support that are so small they 'do not allow for … tracking decay over time' (Gustafson et al., 2022).

In the present study, we account for these factors that might limit the effectiveness of second-order climate communications, shedding light on potential boundary conditions to this strategy. We assess whether a strong second-order belief intervention causally affects a range of climate-related views, behaviour, and perceptions through a nationally representative survey experiment in Germany. Our design leverages public opinion data drawn from real, high-quality surveys. Germany is an ideal test case owing to its 'green image' (Taddicken et al., 2019) and Germans' perception that their country is an 'environmental pioneer' (Schipperges et al., 2016). However, a recent report suggests that German citizens nevertheless do not realise how dominant pro-climate opinion is in their country (Wolf et al., 2023). Could updating these second-order beliefs about pro-climate opinion raise that pro-climate opinion even higher?

We conduct a pre- and post-election panel survey with a high-quality YouGov sample. In the first wave of our survey, half of our respondents were randomly assigned to receive a visually engaging summary of public opinion on climate change in Germany across a range of different specific topics (see Fig. 1), based on recent representative national surveys, and designed in accordance with guidelines on how to communicate climate consensus (Van der Linden et al., 2014, 2017). We

measured second-order beliefs (perceptions of public opinion) once immediately prior to the treatment and once two weeks post-treatment in the second wave. By comparing changes in these second-order beliefs over time and across our treatment and control groups, we verify that our treatment has an enduring impact on people's second-order beliefs, precisely measure that impact relative to pre-treatment beliefs, and then also assess whether such effects are moderated by those prior beliefs. We measure first-order beliefs in both the first wave (immediately post-treatment) and second post-election wave (two weeks later). By comparing the differences in these outcomes.

We go beyond much past work that has often focused on presenting a single (often fabricated) percentage figure summarising public opinion on one particular topic and then measuring that topic at the individual level, by providing a true and clear presentation of broader public opinion on climate change across a range of specific topics, and measuring a range of outcomes at the individual level. By measuring these outcomes at two time points, we also account for the possibility that any effect of second-order information on first-order beliefs can decay over time. Our findings therefore provide novel insight into the broader viability of second-order information as a strategy for combating climate change at the national level, by applying this
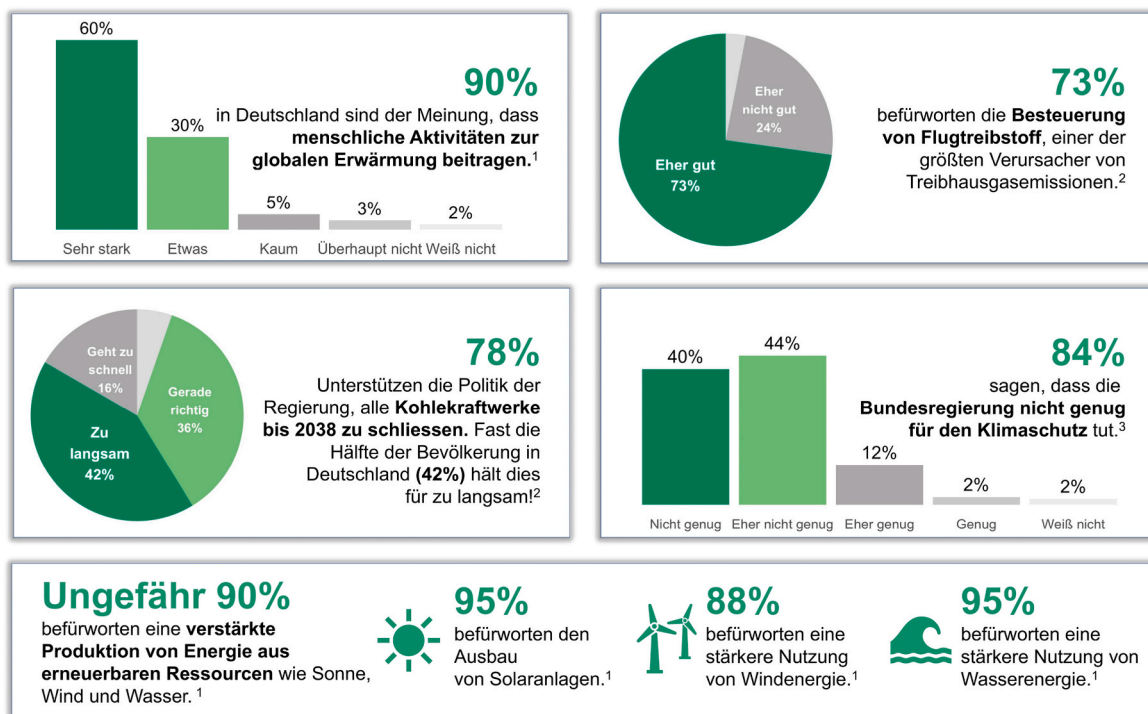
Fig. 1. Second-order climate belief intervention.

Note. **Top**: According to current surveys, the German public are eager for government action against climate change. **Top-left**: 90 % in Germany are of the opinion that human activities contribute to global warming **Top-right**: 73 % are in favour of taxing of aviation fuel, one of the largest contributors to greenhouse gas emissions. **Middle-left**: 78 % support the policy of the government to close all coal-fired power plants by 2038. Almost half of the population in Germany (42 %) think this is too slow! **Middle-right**: 84 % say that the German government is not doing enough for climate protection. **Bottom**: Approximately 90 % are in favour of increased production of energy from renewable resources such as sun, wind and water. 95 % support the expansion of solar installations. 88 % are in favour of greater use of wind energy. 95 % are in favour of greater use of Hydro energy. between the treatment and control groups and how these change over time pre- and post-election, we are able to assess the durability of the effect of updating second-order perceptions on expectations of whether the government will implement pro-climate policies, as well as general beliefs in anthropogenic global warming, attitudes towards those same climate policies, and intentions to adopt environmentally friendly behaviours at the individual level.

approach in a strong but realistic form, while accounting for potential boundary conditions limiting its effectiveness. In doing so, we suggest that if they are to have a measurable impact on public belief in climate change, support for climate policy and uptake of environmentally friendly behaviours, second-order climate interventions may need to be deployed in specific contexts, repeated over time, and targeted at specific segments of the population they are most likely to persuade.

2. Methods

2.1. Participants

We conducted an online survey experiment in Germany around the 2021 Bundestag election. The study was split into pre- and post-election waves. Wave 1 was fielded September 13–21, 2021, and Wave 2 was fielded October 4–13, 2021. The survey sampling (provided by YouGov) implemented nationally representative quotas for gender, age, and region. Respondents were paid a local fee for participating by YouGov.

Wave 1 recruited a total sample of 2801 respondents, 2019 of whom completed Wave 2—a retention rate of 72 %. Sample size was the maximum obtainable within budgetary constraints. Table SI1 in the Supplementary Information provides an overview of the demographics of the sample.

2.2. Materials

2.2.1. Treatment stimulus

Participants in the treatment group were shown the results of recent opinion polls on climate change (Fig. 1). The information was presented on a dedicated page where respondents had to remain for at least 7 s before progressing.

2.2.2. Dependent variables

2.2.2.1. Second-order beliefs.
We prompted respondents as follows: 'We would like to ask you to use the sliders below. These range from 0 to 100. What percentage of citizens in Germany do you think agree with the following statements? If you think that everyone in Germany would say "agree", choose 100. If you think that no one in Germany would say agree, choose 0. If you think that half of all citizens in Germany would say agree, choose 50. You can choose any number from 0 to 100.' The statements were:

- Human activity is the primary cause of global warming.
- The German government needs to implement dramatic action now to fight against climate change.
- Because air travel produces so much in the way of greenhouse gases, a new tax should be imposed on aviation fuel.
- All goods and services in Germany should be taxed based on the amount of greenhouse gas emissions they produce.
- Germany should ban the sale of all new petrol and diesel cars nationwide by 2030.

We also included three additional statements designed to account for the possibility of attitudinal spillover into other, non-environmental policy areas (see Spillover Effects in Supplementary Information). All these items were repeated in the second wave of the survey.

2.2.2.2. First-order beliefs. General beliefs and policy attitudes.
To measure first-order policy attitudes and general environmental beliefs, we prompted respondents, post-treatment, as follows: 'Now we would like to know more about your personal views on climate change and other issues in Germany. Please indicate below to what extent you agree with the following statements'. The statements were the same as those presented for the second-order items, and again we included non-

environmental statements to assess spillover (see Spillover Effects in Supplementary Information).

Policy feasibility. To measure perceptions of how likely it was that different policies would be adopted, we then prompted respondents as follows: 'The Bundestag is constantly dealing with possible new policy measures for Germany. Some of these measures become laws, others do not. Now we would like to ask you about various policy measures that the Bundestag might consider in the next legislature. For each measure, please indicate how likely you think it is to be implemented. Please answer only whether you think the Federal Parliament is likely to implement the measure, and not on whether you personally support or oppose the measure.' The policy measures were as follows:

- A law establishing immediate, drastic measures to combat climate change.
- A law imposing a new tax on air travel.
- A law taxing all goods and services in Germany based on the amount of CO2 they produce.
- A law banning the sale of new petrol and diesel cars by 2030.

Again, we also included potential spillover items in other policy areas. We measured these perceptions on a five-point ordinal scale ranging from very unlikely to very likely.

Behavioural intentions. Next, we measured respondents' electoral expectations (see Green Expectations in Supplementary Information), before finally measuring respondents' behavioural intentions. We asked: 'When you think about the future now, how likely is it that you will implement the following personal actions?'

Respondents considered three 'personal actions':

- I will switch to an energy supplier that uses a fully renewable energy source.
- I will use public transport or the bicycle instead of my car to get to work.
- After the COVID 19 pandemic, I will continue to fly less.

They expressed the likelihood of adopting these behaviours on a five-point scale:

1. Very unlikely
2. Rather unlikely
3. Rather likely
4. Very likely
5. Have already implemented this measure personally

For each behavioural intention analysis, we removed respondents who answered 'have already implemented this measure personally' on that behavioural item, because it is not possible for our treatment to affect a decision that has already been made.

2.2.3. Independent variables
Treatment. Our primary independent variable is a binary indicator of respondents' treatment status.

Priorsecond-order beliefs. Prior to splitting respondents into treatment and control groups, we measured their baseline second-order beliefs on the same 5 second-order items as they would go on to respond to in the second wave (see Dependent variables above). We control for this continuous item in our main effects model in Table 1, to more precisely estimate how our treatment changes these second-order beliefs.

To assess heterogeneity of treatment effects by prior second-order beliefs, for each item, we then classified respondents into tercile groups (33rd, 66th, and 100th percentile of responses)— because we are particularly interested in the size of our treatment effect among those with notably low or high prior second-order beliefs, rather than just whether this effect varies linearly by prior second-order beliefs. For

example, for second-order beliefs about aviation tax, roughly 33 % of respondents believed that 48 % or fewer of the population supported the policy (low prior group), another 33 % believed that this support would be between 49 % and 68 % (medium prior group), and the remaining 33 % believed support would be between 69 % and 100 % (high prior group). We interact the resulting three-level categorical variable with our treatment effect in the models reported in Table 2 and Fig. 3.

Wave. Our wave variable is simply an indicator of the wave in which respondents gave a certain response. We interact this indicator with our treatment effect in the models reported in Table SI12 and SI13.

2.2.4. Covariates

Environmental concern. To measure general levels of concern about climate change, we asked respondents: 'Generally speaking, how concerned are you about environmental issues?' Respondents expressed their concern on a five-point ordinal scale ranging from not at all concerned to extremely concerned. We control for this pre-registered pre-treatment variable in all models reported.

Green Party support. To measure levels of support for green and environmental politics, we asked respondents: 'To what extent do you experience negative or positive feelings when thinking about the following political parties?' We take their answer to this question for the Green Party, reported on a bipolar seven-point scale ranging from 'extremely negative feelings' to 'extremely positive feelings'. We normalise this pre-treatment response so that it ranges from 0 to 1, and control for it in all models reported, as pre-registered.

Demographic controls. We take standard measures, provided by YouGov, of respondent age, gender, and education level. For age, we group respondents into 18–24, 25–44, 45–54, and 55+ groups. For education, we recode responses to simply indicate whether respondents have attended university. We adjust for these pre-registered controls in all models reported.

2.3. Design

We employed a two-wave panel survey experiment with random assignment to treatment and control conditions. The design enabled comparisons of changes in second-order and first-order beliefs both between groups (treatment vs. control) and within respondents over time (Wave 1 vs. Wave 2).

Respondents were randomly assigned, with half receiving the second-order information treatment and half serving as controls.[1]

This design allows estimation of the treatment effect on beliefs, policy attitudes, feasibility perceptions, and behavioral intentions, while accounting for prior beliefs, environmental concern, party support, and demographics.

We obtained ethical approval for this study from FHASS Social Sciences and International Studies Ethics Committee at the University of Exeter (approval 489681). We pre-registered research questions, primary, and secondary analyses on September 29, 2021 at OSF, before receiving any data. We provide our material, data and code on OSF (pre-registration links: https://osf.io/hpe3u/overview, https://osf.io/jp67n/overview; project link: https://osf.io/z6gfa/overview.[2]

2.4. Procedure

1. **Wave 1 (Pre-treatment).** Respondents first reported demographic information, environmental concern, and Green Party support. They then completed the baseline measure of second-order beliefs.
2. **Wave 1 (Treatment/Control).** Respondents were randomly assigned to treatment (viewing second-order climate opinion information) or control (no information). After exposure, both groups completed manipulation checks, and the treatment group additionally reported their level of "surprise."
3. **Wave 1 (Post-treatment).** Respondents then reported first-order beliefs (personal attitudes, feasibility perceptions, behavioral intentions).
4. **Wave 2.** Respondents repeated the measures of second-order and first-order beliefs.

See Supplementary Information Figures SI1 and SI2 for a more detailed visual summary.

2.5. Pre-registration deviations and researcher degrees of freedom

For transparency, in the Supplementary Information, we note and justify a small number of minor deviations from our pre-registered procedure.

3. Results

3.1. Second-order beliefs

Firstly, Fig. 2 shows the distribution of second-order beliefs, measured prior to our experimental stimulus, across five key questions central to attempts to abate increases in global temperature: are humans causing climate change (Anthropogenic global warming); is urgent policy action on the climate necessary (Climate action); should a tax be imposed on aviation fuel (Aviation tax); should a tax be imposed on the CO_2 emissions of products and services (Carbon tax); and should Germany ban the sale of petrol and diesel cars by 2030 (Ban ICE [internal combustion engine] cars). The horizontal bar represents the actual observed percentage of people in our control group who agreed (or strongly agreed) with the statement when we put it to them later in the survey. The circular point represents the median of respondents' second-order beliefs, and the thick vertical bar captures the inter-quartile range.

By this measure, Germans do not substantially or consistently underestimate pro-climate opinion on average. Only for aviation tax is the median second-order belief (53 %) lower than the observed first-order belief (59.8 %), and barely so. In every other case, the median of second-order beliefs is higher than the observed percentage who agree with the item. This difference is most substantial in the case of banning cars and a carbon tax: on average, Germans expect 33 % of people to agree with the former policy and 47 % to agree with the latter; in reality, only 28.1 % and 41 % agree with each respective policy. These observations immediately raise doubts about the likely efficacy of attempting to correct people's beliefs about public opinion on climate change. On average, in most cases, people are not misperceiving pro-climate opinion as lower than it is, as measured in the same survey. This could be a result of Germany's aforementioned 'green image' as an 'environmental pioneer', which may have organically raised second-order beliefs among German citizens who buy into this image.

However, the distributions of these beliefs demonstrate that, although they average out to accuracy in the aggregate, there are large numbers of people who misperceive opinion about climate related issues. For example, while the median error between second-order and first-order beliefs ranges from only approximately 3 (anthropogenic global warming, median error 3.43) to 6 percentage points (carbon tax, median error 5.66), the median of the *absolute* error, treating overestimates and under-estimates as equivalent, is much larger—ranging

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[1] In practice, 1404 participants received the treatment and 1397 did not. Of those, 1003 treated and 1016 untreated respondents completed Wave 2.

[2] In one of these pre-registration documents, we answer the question "Have any data been collected for this study already?" with the option "It's complicated", because our survey had already been conducted. However, YouGov sent our wave 1 dataset via email on October 8, 2021, so although the data collection was completed, we had not received or had sight of any of the resulting data.
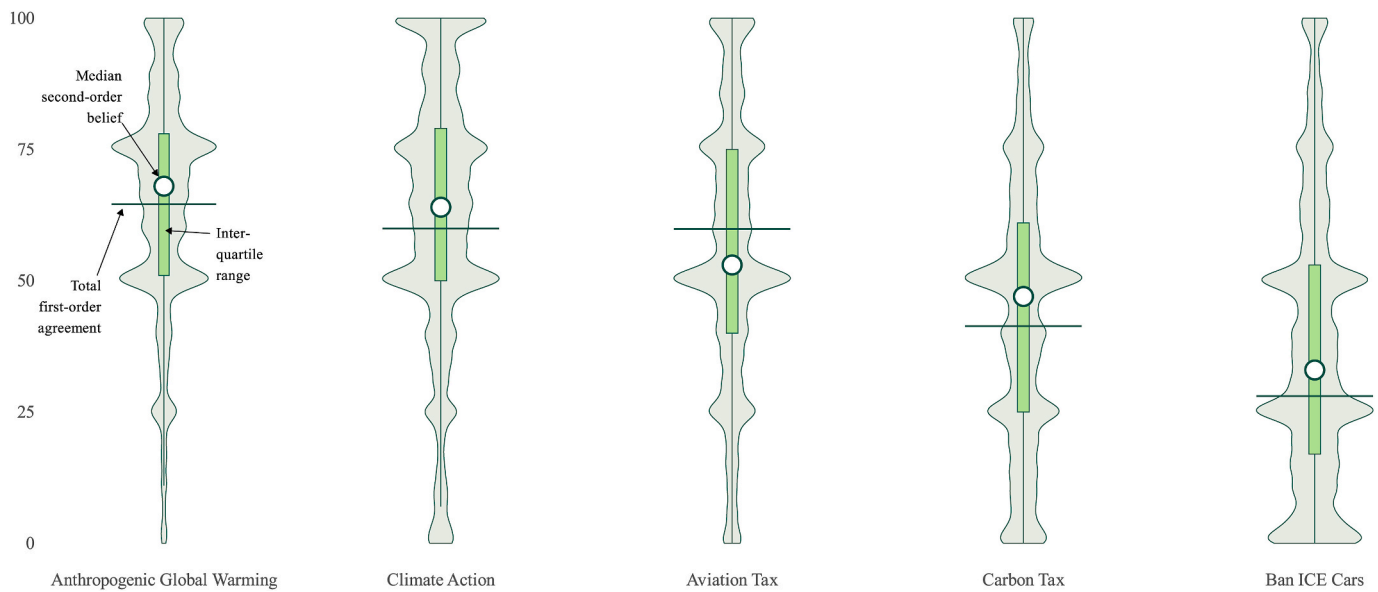
Fig. 2. Germans do not significantly or consistently under-estimate pro-climate opinion on average.

Note. Distributions of baseline, pre-treatment second-order beliefs in first survey wave. Circles show median second-order belief (the median of respondents' perceived percentages of agreement with each item). Horizontal bars show total observed percentage of respondents agreeing with each item (sum of agree and strongly agree, in first wave, only in control group).

from approximately 14 (anthropogenic global warming, 13.56) to over 20 percentage points (ban ICE cars, 20.05). Also, our treatment (Fig. 1 above) was based on the findings of other nationally representative surveys with differently worded items measured on different scales and, in some cases, covering slightly different topics. The percentages of pro-climate beliefs derived from these surveys are larger than those reported in our survey. For example, our treatment included data from the 2019 Politbarometer suggesting that 73 % of Germans thought taxing aviation fuel was a 'rather good' idea, versus the 59.8 % of our sample (in the control group) who agree or strongly agree that this policy 'should be imposed'. Similarly, our treatment features data from a 2019 Pew survey suggesting that 90 % of German people think human activities 'contribute' to global warming (either making a very strong or quite strong contribution), versus the 64.6 % of our control group who agree or strongly agree that human activity is the 'primary' cause. Indeed, a plurality of our treatment group (37.9 %) reported being 'somewhat surprised' by these survey statistics, and roughly one in five of them (19.2 %) were 'very surprised' (see Supplementary Information Table SI4).

Does learning about these high levels of pro-climate opinion cause people to adjust their second-order beliefs, and is this effect stronger for those with the most inaccurate beliefs? Table 1 reports the result of our models estimating the average effect of treatment on each second-order belief, measured two weeks after treatment, and controlling for our raw continuous measure of respondents' pre-treatment second-order belief (along with other pre-registered covariates and demographic controls). In most cases, treatment significantly raises second-order beliefs on average. Two weeks after exposure to our treatment, perceptions of support for all three specific climate policies (aviation tax, carbon tax, and banning cars), and the generalised need for dramatic government action on climate change, are slightly but significantly (2–3 percentage points) higher among the treatment group— relative to those same beliefs measured before the treatment. Net of this treatment effect, there is a consistent and highly significant association between respondents' wave 1 s-order beliefs and those same beliefs reported in wave 2.

However, these small treatment effects could mask substantial heterogeneity based on people's prior beliefs. The treatment might only raise second-order pro-climate beliefs among those who previously perceived pro-climate opinion to be low in the population. To account

for this, Table 2 reports the results of regression models with an interaction term estimating how the effect of treatment varies among people with different prior second-order beliefs. In this case, for each outcome, respondents are split into low, medium, and high tercile groups based on their pre-treatment second-order beliefs. The *Treatment* effect reported in Table 2 is the effect among those with the lowest prior second-order beliefs—those we might expect to be most strongly affected—and the interaction effects measure how this effect changes among the medium and high tercile groups. To ease interpretation of these interaction terms, Fig. 3 plots the marginal effect of treatment on each outcome, for each prior tercile group, derived from these models. Fig. 3 shows that the treatment had no discernible effect on second-order beliefs among those who already thought support was high. Even though some members of this group likely *over*-estimated beliefs in some cases, our treatment had no overall meaningful 'boomerang effect' in which it lowered perceptions (Schultz et al., 2007)—possibly, again, as Germany's 'green image' as an 'environmental pioneer' has consolidated these perceptions to a point where they are not susceptible to reversion from a single treatment. However, in all cases except for banning ICE cars, treatment had substantial and significant effects on those who believed that support was low. The largest effect observed is for Carbon Tax, where treatment raised perceptions of support by approximately 8 percentage points. The interaction effects in Table 2 further show that the difference between the treatment effect on the low and high prior groups is itself statistically significant in the case of climate action, aviation tax, and carbon tax. As for those whose prior second-order beliefs fell between the two extremes, there is only evidence of an effect of treatment for the aviation tax and banning ICE cars outcomes.

Overall, we therefore find evidence not only that our treatment very slightly but significantly raised most second-order pro-climate beliefs on average even two weeks after exposure, but that this effect was driven largely by raising the beliefs of those who had previously most under-estimated pro-climate public opinion.

3.2. First-order beliefs

But can the same intervention also alter individuals' own climate beliefs and behaviours? Tables 3 and 4 report the results of regression models estimating the effect of treatment on first-order climate
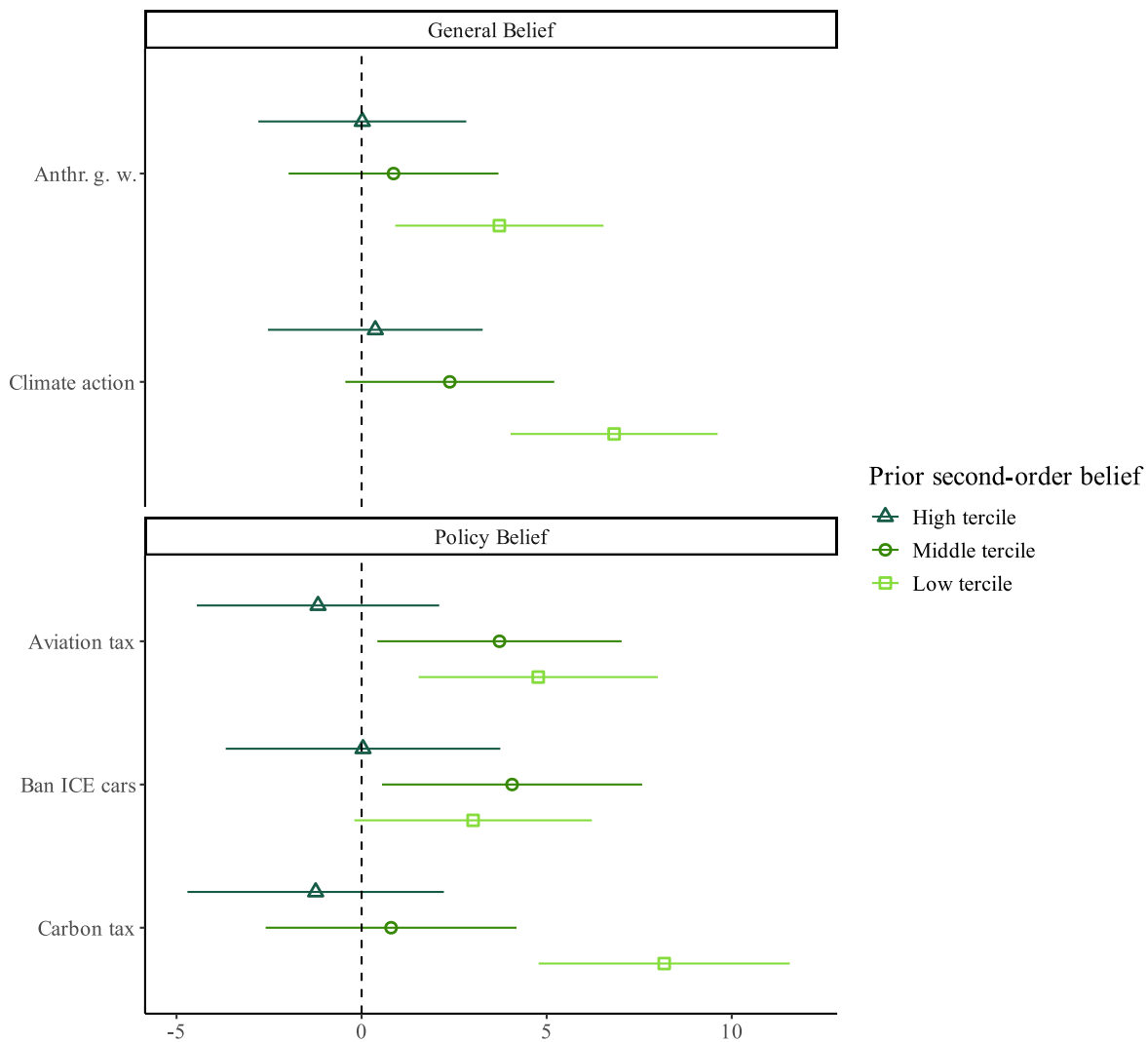
Fig. 3. Heterogeneous effects on second-order beliefs.
Note. Each effect is estimated on a subgroup of respondents determined by their prior second-order beliefs. Top panel shows effects on generic climate beliefs (caused by humans, action required), bottom panel shows effects on climate policy beliefs (aviation tax, banning ICE cars, carbon tax). Treatment effects are strongest on those who reported lower prior second-order beliefs.

Table 1
Results of regression models estimating effect of treatment on wave 2 s-order beliefs, with pre-registered covariates and demographic controls. 95 % confidence intervals included.

	Anthr. g. w. (1)	Climate action (2)	Aviation tax (3)	Carbon tax (4)	Ban ICE cars (5)
Treatment	1.551 (−0.038, 3.141)	3.174*** (1.626, 4.723)	2.317* (0.481, 4.154)	2.802** (0.852, 4.751)	2.321* (0.368, 4.274)
Wave 1 response	0.429*** (0.388, 0.470)	0.506*** (0.468, 0.544)	0.487*** (0.449, 0.526)	0.456*** (0.415, 0.497)	0.480*** (0.440, 0.520)
Intercept	26.265*** (20.642, 31.889)	14.627*** (9.273, 19.982)	14.532*** (8.243, 20.820)	12.867*** (6.371, 19.363)	15.095*** (8.452, 21.738)
Pre-registered controls	✓	✓	✓	✓	✓
Observations	1744	1757	1719	1603	1714
Adjusted R²	0.324	0.512	0.327	0.333	0.338

Note: *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

outcomes. These models are fit to the full wave 1 sample, including those who did not go on to complete wave 2 of the survey, to maximise power. In Supplementary Information Table SI3, we show that attrition is not associated with treatment or any prior second-order beliefs, allaying any concerns about sample attrition bias.

We find that the treatment is able to immediately positively affect expectations about the scope of policies that are politically feasible. Those who were shown our treatment were slightly but significantly more likely to say that the German Federal Parliament would implement

'a law that establishes immediate, drastic measures to combat climate change' (climate action), 'a law imposing a new tax on air travel' (aviation tax), and 'a law taxing all goods and services in Germany based on the amount of CO2 they produce' (carbon tax). As the pre-registered heterogeneity analysis shows in Table 5, in the case of the perceived feasibility of general, immediate climate action, the effect may be driven by those with the lowest prior second-order beliefs. The overall impression of high public support for climate action may have convinced those respondents for whom this information was most out-of-step with

Table 2

Results of regression models with interaction estimating effect of treatment on wave 2 s-order beliefs depending on prior second-order beliefs. 95 % confidence intervals included.

	Anthr. g. w. (1)	Climate action (2)	Aviation tax (3)	Carbon tax (4)	Ban ICE cars (5)
Treatment	3.722** (0.909, 6.535)	6.823*** (4.026, 9.619)	4.773** (1.543, 8.003)	8.176*** (4.783, 11.569)	3.013 (−0.196, 6.222)
Medium prior	11.628*** (8.694, 14.563)	14.381*** (11.476, 17.285)	12.850*** (9.522, 16.179)	16.777*** (13.316, 20.237)	13.656*** (10.211, 17.101)
High prior	20.981*** (18.108, 23.855)	27.568*** (24.471, 30.666)	29.822*** (26.531, 33.114)	31.507*** (27.968, 35.045)	29.813*** (26.270, 33.355)
Intercept	38.296*** (32.716, 43.877)	22.968*** (17.259, 28.677)	23.205*** (16.697, 29.714)	14.362*** (7.732, 20.991)	18.260*** (11.419, 25.101)
Pre-registered controls	✓	✓	✓	✓	✓
Treatment × Medium prior	−2.859 (−6.861, 1.143)	−4.440* (−8.416, −0.464)	−1.048 (−5.666, 3.571)	−7.379** (−12.177, −2.582)	1.053 (−3.706, 5.812)
Treatment × High prior	−3.703 (−7.678, 0.272)	−6.453** (−10.485, −2.420)	−5.951* (−10.551, −1.350)	−9.418*** (−14.267, −4.569)	−2.975 (−7.881, 1.931)
Observations	1744	1757	1719	1603	1714
Adjusted R^2	0.295	0.454	0.290	0.318	0.309

Note: *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

Table 3

Results of regression models estimating immediate effect of treatment on policy feasibility in wave 1, with full wave 1 sample. 95 % confidence intervals included.

	Policy feasibility			
	Climate action (1)	Aviation tax (2)	Carbon tax (3)	Ban ICE cars (4)
Treatment	0.110** (0.030, 0.190)	0.149*** (0.073, 0.225)	0.092* (0.015, 0.170)	−0.001 (-0.083, 0.080)
Intercept	2.850*** (2.605, 3.095)	3.126*** (2.893, 3.359)	2.763*** (2.525, 3.001)	2.507*** (2.257, 2.757)
Pre-registered controls	✓	✓	✓	✓
Observations	2690	2691	2691	2691
Adjusted R^2	0.006	0.009	0.004	0.007

Note: *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

Table 4

Results of regression models estimating immediate effect of treatment on first-order outcomes (anthropogenic global warming belief, policy attitudes, and behavioural intentions) in wave 1, with full wave 1 sample. 95 % confidence intervals included.

	Anthr. g. w. (1)	Policy attitudes				Behavioural intentions		
		Climate action (2)	Aviation tax (3)	Carbon tax (4)	Ban ICE cars (5)	Energy supplier (6)	Fly less (7)	Public transport (8)
Treatment	0.016 (-0.053, 0.085)	0.044 (-0.017, 0.105)	0.026 (-0.055, 0.108)	0.001 (-0.076, 0.077)	0.030 (-0.053, 0.113)	−0.005 (-0.077, 0.068)	0.087 (-0.009, 0.183)	−0.010 (-0.101, 0.080)
Intercept	1.955*** (1.743, 2.167)	1.557*** (1.370, 1.744)	1.744*** (1.494, 1.994)	1.487*** (1.253, 1.721)	1.317*** (1.062, 1.572)	1.540*** (1.332, 1.749)	1.423*** (1.146, 1.699)	1.851*** (1.586, 2.117)
Pre-registered controls	✓	✓	✓	✓	✓	✓	✓	✓
Observations	2690	2690	2690	2691	2691	2176	1884	2002
Adjusted R^2	0.528	0.225	0.276	0.317	0.346	0.176	0.126	0.105

Note: *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

their prior perceptions that such action was possible, without spilling over into convincing them that any *particular* policy measure was more likely to be introduced. However, by the second wave, all effects had dissipated with *no remaining significant differences* on these policy expectation measures for those who received the second-order treatment condition (see Supplementary Information Table SI12).[3]

Table 4 shows that treatment had no effect on belief in anthropogenic global warming, support for pro-climate government policies (taking action, implementing an aviation tax, imposing a carbon tax, banning ICE cars), or individual-level behaviours (switching energy supplier, flying less, using public transportation).[4] As Table 6 further shows, the treatment even fails to move first-order global warming

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[3] In the Supplementary Material, we show that defining the treatment group as those who spent a minimum amount of time observing the treatment (either 10 s or the median time of 27.909 s), and defining all other respondents as untreated, the effect of treatment on the perceived feasibility of an aviation tax remains significant in the second wave.

[4] Unregistered exploratory analyses in the Supplementary Material (Tables SI14 and SI15), however, find that those in the treatment group who spent more time consulting the treatment had more positive perceptions of the feasibility of an aviation tax and support for such a tax, higher levels of belief in anthropogenic global warming, stronger support for political action on climate change, and greater intention to fly less. It is, of course, possible that these associations are due to reverse causality: those with more pro-climate views may be likely to spend more time consulting pro-climate information such as that in our treatment.

Table 5

Results of regression models with interaction estimating effect of treatment on wave 1 perceived policy feasibility depending on prior second-order beliefs. 95 % confidence intervals included.

	Policy feasibility			
	Climate action (1)	Aviation tax (2)	Carbon tax (3)	Ban cars (4)
Treatment	0.326*** (0.185, 0.466)	0.137* (0.001, 0.272)	0.120 (-0.026, 0.267)	0.039 (-0.096, 0.174)
Prior second-order beliefs				
Baseline: low prior				
Medium prior	0.344*** (0.198, 0.490)	0.118 (-0.019, 0.256)	0.136 (-0.012, 0.284)	0.319*** (0.174, 0.465)
High prior	0.593*** (0.438, 0.748)	0.226** (0.087, 0.364)	0.301*** (0.149, 0.453)	0.646*** (0.498, 0.795)
Intercept	2.810*** (2.541, 3.079)	3.225*** (2.968, 3.481)	2.676*** (2.407, 2.944)	2.366*** (2.098, 2.635)
Pre-registered controls	✓	✓	✓	✓
Treatment × Prior interactions				
Treatment × Medium prior	−0.318** (-0.517, −0.119)	0.079 (-0.114, 0.271)	−0.024 (-0.229, 0.182)	−0.031 (-0.232, 0.169)
Treatment × High prior	−0.291** (-0.495, −0.088)	−0.042 (-0.236, 0.152)	0.007 (-0.200, 0.214)	−0.095 (-0.302, 0.112)
Observations	2498	2468	2346	2462
Adjusted R^2	0.032	0.017	0.017	0.053

Note: *p < 0.05; **p < 0.01; ***p < 0.001.

Table 6

Results of regression models with interaction estimating effect of treatment on wave 1 first-order outcomes depending on prior second-order beliefs. 95 % confidence intervals included.

	Anthr. g. w.	Policy attitudes			
		Climate action	Aviation tax	Carbon tax	Ban ICE cars
Treatment	0.060 (-0.058, 0.178)	0.089 (-0.013, 0.191)	0.102 (-0.031, 0.236)	0.087 (-0.046, 0.220)	0.066 (-0.059, 0.191)
Prior second-order beliefs					
Medium prior	0.554*** (0.434, 0.675)	0.378*** (0.272, 0.483)	0.649*** (0.514, 0.784)	0.638*** (0.505, 0.772)	0.623*** (0.489, 0.757)
High prior	0.797*** (0.677, 0.918)	0.638*** (0.526, 0.750)	1.292*** (1.156, 1.429)	1.230*** (1.093, 1.368)	1.436*** (1.299, 1.573)
Intercept	1.671*** (1.450, 1.893)	1.446*** (1.251, 1.641)	1.505*** (1.253, 1.757)	1.140*** (0.897, 1.382)	0.961*** (0.714, 1.209)
Pre-registered controls					
Treatment × Prior interactions					
Treatment × Medium prior	−0.058 (-0.223, 0.108)	−0.045 (-0.189, 0.100)	0.059 (-0.130, 0.249)	−0.018 (-0.203, 0.168)	0.108 (-0.077, 0.293)
Treatment × High prior	−0.039 (-0.206, 0.127)	−0.054 (-0.202, 0.093)	−0.227* (-0.418, −0.036)	−0.232* (-0.419, −0.045)	−0.228* (-0.419, −0.037)
Observations	2479	2498	2467	2346	2462
Adjusted R^2	0.427	0.581	0.368	0.413	0.474

*p < 0.05; **p < 0.01; ***p < 0.001.

beliefs and policy preferences for those who had low second-order beliefs—whose second-order beliefs were most responsive to our treatment—as well as those with medium or high prior second-order beliefs on these topics (where in some cases the effect of treatment appears to be even smaller).[5] Accordingly, there was also no durable shift in these other first-order outcomes two weeks later (see Supplementary Information Table SI13).

4. Discussion

It is commonly argued that a widespread tendency to underestimate aggregate pro-climate opinion is a barrier to climate action and pro-climate belief at the individual level (Andre et al., 2024; Ballew et al., 2019; Goldberg, van der Linden, et al., 2020; Mildenberger & Tingley, 2019). Correcting these second-order beliefs should, therefore, improve these first-order pro-climate outcomes. We have challenged this argument in two ways, suggesting that second-order communications of this nature may have important, often overlooked, boundary conditions.

First, we found that German people did *not* substantially underestimate pro-climate beliefs among the German population. Our sample, on average, quite accurately estimated levels of pro-climate opinion in Germany—a country with a strong 'green image' as an 'environmental pioneer'. This may have limited the effect of our intervention on second-order beliefs and, consequently, first-order beliefs. Nonetheless, at the individual level, there is significant heterogeneity in the accuracy of second-order beliefs. In such a context, second-order interventions may not be useful for the wider population, but could provide useful information to those who most underestimate the prevalence of climate opinion. However, this strategy is further complicated by Leviston et al. (2013)'s observation that climate change deniers typically *over-estimate*

the proportion of the Australian population that shares their belief, whereas people who believe in human-caused climate change *under-estimate* the proportion of the Australian population that shares their belief. This finding implies that the group of people with low second-order climate beliefs is likely to comprise both those with very positive and very negative first-order climate beliefs. Research by Andreotta et al. (2022) suggests that it is difficult to persuade either of these groups to change their minds about climate change, and that climate policy initiatives are most effective on those who sit on the fence. Future research should consider adopting audience segmentation approaches to identify these fencesitters, establishing the extent to which they underestimate pro-climate belief in the population, and assessing whether correcting these second-order beliefs can turn them into more committed pro-climate actors.

Second, we indeed found that a strong, unambiguous informational stimulus—that slightly but durably raised their perceptions of how widespread such pro-climate opinion is across Germany—had no discernible or lasting effect on other individual-level beliefs, although it may have temporarily raised expectations that certain climate policies might be implemented. Extending the point above, these limited effects could stem from tension inherent in the idea of using second-order information to affect first-order beliefs at a societal scale. As our interventions reported to respondents, the German public already display very high support for climate change policy and belief in anthropogenic global warming. We were therefore able to design an effective treatment by reporting these high levels of support back to the citizens themselves. While a strong signal, this also means few respondents were erstwhile climate sceptics whom the treatment could persuade. Future research should extend our approach to contexts with slightly lower levels of pro-climate opinion, to investigate whether and how the effect of second-order information changes when that information is potentially less persuasive, but there are more people available to persuade.

Indeed, any significant effects our intervention had on first-order beliefs faded two weeks post-treatment. A first possible explanation for this decay is that the information fades from memory over time. In real-world contexts it is possible that such messages would be communicated to the public more than once, producing a larger effect over time

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[5] Note that we do not analyse whether prior second-order beliefs moderate the effect of treatment on our behavioural intentions outcomes because these outcomes have no directly corresponding second-order belief measure.

through repeated exposure (Van der Linden et al., 2017). Such repetition—potentially through different media channels in different, engaging forms—could consolidate the effect of the information on second-order beliefs and, consequently, first-order outcomes. While our one-off treatment does not allow us to assess this possibility directly, the (likely confounded) exploratory analyses in the Supplementary Material showing that those who spent more time consulting our treatment scored higher on some first-order measures may suggest that second-order interventions that keep people engaged may have some potential to improve climate outcomes. A second possible explanation is that, as our fieldwork was conducted prior to and in the aftermath of an election, the informational cue given by the election result itself essentially washed out any effect of our one-off infographic. While we have no direct evidence to support this explanation, it seems particularly compelling given that the ephemeral first-order effects we observed were on perceptions of whether certain environmental policies could be implemented by the next government. Knowing how the parties performed at the election, and which are likely to form a government, likely shapes these perceptions more strongly than pre-election second-order information about climate beliefs. However, in the Supplementary Material, an exploratory analysis finds that levels of knowledge about the election result do not seem to moderate the reversion of the effect of treatment over the two waves. It is nonetheless worth conducting studies across different information environments to account for the possibility of any such "history effect". A third possible explanation for these effects decaying over time is that any initial effect may have simply been a "placebo effect". As our analyses simply compare outcomes in a treatment group to a pure control group, we cannot rule out the possibility that the difference is not due to the content of our treatment, but merely to the presence of a treatment of any kind, even an ineffective one. We could reasonably expect such a placebo effect to fade where a true treatment effect may have lasted.

The nature of our second-order intervention may also have limited its effect. Recent research suggests that communicating expert rather than public consensus (Van der Linden, 2021) or conveying minority trending norms rather than majority norms (Mortensen et al., 2019) are effective strategies for leveraging opinions to influence opinions. In simply reporting static measures of recent public opinion, our design did not utilise either strategy. Future research could extend our approach by comparing the effects these different forms of information, and different combinations of them (see, e.g., Bolsen et al., 2014; Van Der Linden, 2015).

Finally, the first-order outcomes we measured may not have been particularly responsive to our second-order intervention. These outcomes did not always directly correspond to the measures reported in the treatment itself. For example, we did not measure support for expansion of renewable energy sources, despite reporting such support in our treatment. While testing the effects of second-order information on a broad array of specific climate topics on a similarly broad array of first-order outcomes enabled us to assess limits of the potential scope of the effect of second-order interventions, this arguably also makes for a fairly conservative test. Theoretically, it is likely to be easier to influence first-order outcomes in areas that exactly match those for which the second-order information is presented.

CRediT authorship contribution statement

Matthew Barnfield: Writing – review & editing, Writing – original draft, Visualization, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Paula Szewach:** Writing – review & editing, Methodology, Investigation, Conceptualization. **Sabrina Stöckli:** Writing – review & editing, Project administration, Methodology, Investigation, Formal analysis, Data curation. **Florian Stoeckel:** Writing – review & editing, Visualization, Methodology, Investigation, Conceptualization. **Jack Thompson:** Writing – review & editing, Methodology, Investigation, Data curation, Conceptualization. **Joseph Phillips:** Writing – review & editing, Methodology, Investigation, Data curation, Conceptualization. **Benjamin Lyons:** Writing – review & editing, Methodology, Conceptualization. **Vittorio Mérola:** Writing – review & editing, Methodology, Investigation, Conceptualization. **Jason Reifler:** Writing – review & editing, Visualization, Supervision, Methodology, Investigation, Data curation, Conceptualization.

Ethics approval and consent to participate

Consent for publication

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The authors have no conflicts of interest to disclose.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvp.2026.102901.

Data availability

We provide data and code to reproduce our analyses on OSF: https://osf.io/z6gfa/?view_only=9e77340a33134cd0bcbea1e48918a220.

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