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Changing seasonal temperature offers a window of opportunity for stricter climate policy

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ABSTRACT

Environmental catastrophes, including the increased severity and frequency of climate extremes, can act as "windows of opportunities" that challenge citizens' mental models and motivate them to engage in reflective processes, challenging their pre-conceived ideas. Less well understood is whether experiencing changing weather conditions, common in mid-latitudes, can have a similar effect and increase the citizens' concerns about climate change and their willingness to accept more stringent climate policies. In this paper, we investigate the effects of changing seasonal temperature on the perceived seriousness of climate change and willingness to mitigate climate change. We use data from four yearly waves of a spatially explicit representative population survey in Germany and weather records from the postal code areas in which they live. To our knowledge, this study is the first analysis to link individual perceptions towards climate change and different mitigation options with seasonal temperature changes at specific locations in Europe. The analyzed perceptions were strongly influenced by socio-demographic characteristics and broader societal changes, as well as individual experiences of seasonal temperatures. The results show that experienced seasonal temperature change influences personal climate change concerns as well as the willingness to mitigate climate change, although with a weaker effect. The results indicate that it is the absolute temperature variation experienced that is important, rather than whether it is getting colder or warmer than usual. Considering the influences identified in this study can offer a window of opportunity for more stringent and targeted climate change policy.

1. Introduction

The experience of climate change and events that are conceptualized as impacts of climate change, have the potential to shape human understanding, attitudes and risk assessment of global environmental changes (Kundzewicz et al., 2020; Otto-Banaszak et al., 2011). Enhanced climate mitigation measures require far-reaching political action and their successful implementation strongly depends on public opinion and pressure (Agnone, 2007). Understanding public opinion on climate change and how it is influenced is therefore essential to not only get a clear picture of the status quo but to also predict trends, and identify possible "windows of opportunity" for successful climate change policy implementation and communication (Sisco et al., 2017). Several authors point out, that environmental catastrophes, including increased severity and frequency of climatic extremes, might act as "windows of opportunity" that give rise to uncertainty and confusion, which might, in turn, motivate actors to engage in reflective processes and challenge their pre-conceived ideas (Burns, 1994; Cremades et al., 2018). Also at the individual level, life events that disrupt everyday habits might open up a window in which individual behavior is more likely to be deliberately reconsidered (Schäfer et al., 2012; Verplanken and Wood, 2006). Such opportunities are usually triggered by unpredictable external or environmental factors (Otto et al., 2020), however, it is important to work on social complexities such as public acceptance and support for proposed transformational changes. This can help a process of creative destruction (Schumpeter, 2010) by preparing new social structures to replace old ones.

Most previous studies in the European context have addressed the impact of extreme events on public opinion (Demski et al., 2017; Gärtner and Schoen, 2021; Kreibich, 2011; Spence et al., 2011; Taylor et al.,

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2014a,b; von Möllendorff and Hirschfeld, 2016; Janko et al., 2018). For this reason, we do not yet fully know whether temperature changes that are less dramatic but, nonetheless, affect practically everyone can also influence public attitudes toward climate change and climate mitigation. The main objective of this study was to identify the impact of changes in externally measured seasonal temperature on an individual's opinion about climate change and their support for climate policy, considering the individual's characteristics and prior beliefs. We asked whether the way individuals experience variations in seasonal temperatures affects their opinions about the severity of climate change and their support for mitigation policy. The study advanced our knowledge in this area by making use of a representative longitudinal dataset collected from a population in Germany by the GESIS Panel (GESIS, 2019) and a high-quality interpolation of weather and climate observations made at Deutscher Wetterdienst weather stations, which was available at the Potsdam Institute of Climate Impact Research (Potsdam Institute for Climate Impact Research, 2019). Germany is one of the largest countries in the European Union in terms of its area, population size and economic production; as such, it is also one of the countries with the largest greenhouse gas emissions (IEA, 2022). The country plays an active role in European Union environmental and climate policy, and its active environmental social movements are known to shape the country's politics (Renn and Marshall, 2016; Smith et al., 2020). In 2011, after the Fukushima nuclear disaster, public protest led to a rapid shift in domestic energy production known as the 'Energiewende' (Smith et al., 2020). The German population has been subject to several studies exploring the links between the political orientation, values, personal characteristics, and environmental and climate perceptions, attitudes and behavioral choices. As an example, Engels et al. (2013) used population survey data from Germany to analyze the links between public climate-change skepticism, energy preferences and political participation. The study results indicate that climate-change skepticism correlates negatively with support for renewable energy resources and political participation, although this skepticism has not diffused widely in Germany. Smith et al. (2020) analyzed German society panel data and investigated the relationship between knowledge, concern and individual willingness to make behavioral changes in response to polar ice loss. The authors found that the concern for the polar regions is the strongest predictor for the willingness of an individual to make behavioral changes in response to polar ice loss. A study by Gärtner and Schoen (2021) identified no significant effect of weather extremes on climate change perceptions in Germany.

Personal experiences with weather and their influence on climate change perceptions have been addressed by a growing body of literature since the early 2000 s (Marquart-Pyatt et al., 2014). This pathway of investigation is still new and limited in terms of which kind of weather, climate extremes and parts of the world reviewed, and the data and methods used. The main focus of previous research has been on the USA (Akerlof et al., 2013; Borick and Rabe, 2014; Donner and McDaniels, 2013; Egan and Mullin, 2012; Hamilton and Stampone, 2013; Li et al., 2011; Marquart-Pyatt et al., 2014; Myers et al., 2012; Ray et al., 2017; Zanocco et al., 2018); only a few can be found for the UK (Demski et al., 2017; Spence et al., 2011; Taylor et al., 2014a), or other European countries (Howe, 2018; Janko et al., 2018; Gärtner and Schoen, 2021; Kreibich, 2011; Shum, 2012; von Möllendorff and Hirschfeld, 2016). Several studies, however, suggest that results in temperate climate zones, that are typical for northern and central Europe, differ slightly from the findings from warmer and less temperate climates, and emphasize the need for country-specific approaches (Taylor et al., 2014a,b). While some of the studies use perceived (subjective) experiences of climate change, others use observed (objective) weather and climate experiences to draw their conclusions.

Gärtner and Schoen (2021) conducted a mixed-effects regression with German panel data and objective weather observations, hence followed a similar study design as proposed in this article. Their study could not find an effect of weather extremes on climate change perceptions. Weather extremes are still rare and more moderate in the investigated climate zone compared to world regions most affected by climate change. Hence our attention focuses on continuous and more subtle changes of seasonal temperature conditions, which might be more relevant for understanding the influence of climate change on climate change perceptions and policy attitudes.

This study is to our knowledge the first analysis to link individual perceptions towards climate change and different mitigation options with measured seasonal temperature changes at specific locations in Europe. Its small geographical roster on a national scale is novel to previous international research.

First, background information is provided to describe the association between an individual's experience of weather phenomena and their perceptions of climate change. We then outline the method and the data used in the study, present the study results, and finally present a discussion and conclusion based on these results.

2. The influence of weather phenomenon experience on climate change perceptions and attitudes towards mitigation policy

Over the past decade, numerous studies have appeared on shared knowledge, personal opinions and risk perceptions regarding climate change, with several placing a specific focus on Germany. Diekmann and Preisendörfer (2003) showed that, already in the early 2000 s, environmental problems were an emotionally charged topic in Germany: 74% of survey respondents expressed fear about the environmental conditions and their effects on future generations, and 66% expected an environmental catastrophe to occur, if the style of living was maintained. Fifty-four percent of the respondents that time agreed that people should be willing to lower their standard of living, and 27% opted for environmental protection measures, even if these cost jobs. More recently, Ziegler (2017) reported that 78% of Germans believed that climate change was already occurring, while nearly three-quarters supported additional federally funded climate protection measures. This author also pointed out that his research indicated that a Green Party affiliation was positively related to support for climate change policy and a willingness to pay for environmentally friendly products. Socio-demographic determinants, such as age, gender and education, also seem to affect dispositions towards climate change. Smith et al. (2020) found that one-third of all Germans felt somewhat or very well informed about polar ice loss (31%), while more than half of all Germans were not concerned about polar ice loss. However, a substantial share of German respondents reported that they were willing to drive less to reduce carbon emissions (41%). As correctly pointed out by Kollmuss and Agyeman (2002), a person's environmental consciousness is influenced by a whole range of factors that affect their environmental knowledge, values and attitudes. These, in turn, are embedded in broader personal values and shaped by personality traits, as well as other internal and external factors. Although the access to information is important for shaping environmental attitudes, this effect is moderated by trust in science and trust in the source of messages (Diamond et al., 2020).

Research has shown that many of an individual's opinions about climate change and willingness to mitigate are influenced by specific factors, such as their gender, age, political identity, education and economic status (Akerlof et al., 2013; Borick and Rabe, 2014; Egan and Mullin, 2012; Hamilton and Stampone, 2013; Howe, 2018; Myers et al., 2012). A growing number of studies are being carried out to investigate the effects of changing or extreme weather and climatic conditions on such perceptions. Researchers analyzing the relationships between perceptions of climate change and externally measured climate conditions, however, have predominantly focused on populations in the USA (Donner and McDaniels, 2013; Egan and Mullin, 2012; Hamilton and Stampone, 2013), while those conducted in Europe have mostly focused on people's experiences in extreme floods (Demski et al., 2017; Kreibich, 2011). Few European studies have investigated the effect of the

observed temperature data on climate change perceptions, but these have been carried out on the collective level by using national averages (Howe, 2018; Shum, 2012) and have generally disregarded individual's experiences and opinions. Only Gärtner and Schoen (2021) conducted a German study on an individual level on small spatial scales, however exclusevley investigating weather extremes. Country-specific studies, however, are important, since climate change perceptions and how these perceptions change over time vary greatly between different countries. The climate change perceptions in the USA, for example, unlike those in Germany, have been subject to strong fluctuations despite the growing amount of scientific knowledge on this topic (Myers et al., 2012; Borick and Rabe, 2014).

The studies reviewed range in scale from explicit location (Zanocco et al., 2018), to county or even climate zones (Marquart-Pyatt et al., 2014). The extremes included in these datasets are often limited to single or very few event types. Just as many studies use single survey social data (Akerlof et al., 2013; Demski et al., 2017; Ray et al., 2017; Zanocco et al., 2018) as social data from time-series surveys (Borick and Rabe, 2014; Donner and McDaniels, 2013; Egan and Mullin, 2012; Hamilton and Stampone, 2013; Marquart-Pyatt et al., 2014), however very few made use of a longitudinal dataset (Gärtner and Schoen, 2021; Howe, 2018; Myers et al., 2012). Several papers call for longitudinal data analysis in the future to "clearly distinguish between the role of personal weather experience and other correlates" (Donner and McDaniels, 2013) (see also Borick and Rabe, 2017; Demski et al., 2017).

There are two major streams of research, which differ in whether the individual experience of climate change is self-reported or derived from climatic and weather observations. The research stream of perceived experience of climate change, surveys an individual's subjective opinion on the matter. It indicates how many people believe they have personally experienced climate change, which events they conceptualize as being the result of climate change, and the relationship between these perceived experiences and opinions on climate change. The findings of a large body of literature reveals that the majority of people surveyed, report that they have experienced some form of event they associate with climate change (Reser et al., 2014). While in the USA most respondents reported experienced changes to seasons as an impact resulting from climate change (Akerlof et al., 2013), respondents from the UK report an increasing experience in flooding, periods of heavy rainfall, coastal erosion and mild winters and a decrease in heat waves and hot summers (Taylor et al., 2014a,b). Understanding how people conceptualize climate change is of great importance, since many studies suggest that only events associated with climate change impact climate change opinion (Borick and Rabe, 2014).

In contrast to perceived experience studies, the stream of research investigating the impact of observed weather and climatic conditions on climate change opinion uses objective meteorological data to investigate whether certain specific climatic variabilities and weather events have an influence on an individual's opinion. There is evidence that prior beliefs skew perceptions about experienced weather and climate change through processes such as mental models and motivated reasoning (Borick and Rabe, 2017; Hamilton and Stampone, 2013; Hart and Nisbet, 2012; Myers et al., 2012; Zanocco et al., 2018). Howe (2018) analyzed how the perceived temperature deviation of two Norwegian winters depended on individual characteristics as well as prior beliefs. Furthermore, he tested the accuracy of this evaluation compared to observed weather data. He concluded that respondents on average recall seasonal temperature variation accurately, however they are slightly influenced by their prior beliefs. Mental models can be described as a mechanism of how to perceive and interpret your environment, retrieve memorized information and apply this knowledge to problem solving (Denzau and North, 1994; Otto-Banaszak et al., 2011). Since mental models are flexible and manipulable (Senge, 1990) they can be corrected for flaws or uncertainties which cause unpredicted events. They are therefore seen as drivers for learning and action. Motivated reasoning refers to a cognitive process in which the search of an individual's memory might "occur selectively in order to support a pre-desired conclusion" (Leviston et al., 2014, p. 442). The psychological distance of an individual to an object or event influences how it is perceived and addressed (Singh et al., 2017; Spence et al., 2012). While the dilemma of climate change is its complexity and uncertainty, making it difficult to draw clear conclusions between action and impact (Otto-Banaszak et al., 2011), personal experiences can reduce psychological distancing. Research has shown that climate action is discouraged when climate change is considered to be psychologically distant and perceived as abstract, less real or irrelevant (McDonald et al., 2015; Spence et al., 2012).

3. Data

To draw conclusions on the influence of environmental conditions on social processes, our analysis must combine two datasets: one representing the attitudes and socio-demographic conditions and the other the local environmental conditions of each respondent. These datasets are combined through a shared georeferenced variable.

3.1. Panel data: climate change concern and willingness to mitigate

Dependent and socio-demographic variables for this analysis are taken from the longitudinal dataset of the Gesis Panel of the GESIS Leibniz Institute for the Social Sciences (GESIS, 2018). The Gesis Panel dataset was chosen due to its high-quality execution, relevant questions for this analysis, large numbers of representative responses and its panel character. The panel surveys approximately 4400 randomly selected permanent German residents aged between 18 and 70 years. The panelists are repeatedly surveyed in six waves every year.

Due to availability restrictions, only the data from the start of the panel in 2014 until 2018 is used. In this timeframe a total of 5543 respondents answered one or more waves of the Gesis Panel. In order to work with a complete dataset, in which all variables used were answered every year, non-complete responses were cut from the analysis, which reduced the sample size to 1799 respondents. The subsample of the Gesis Panel used was compared to the socio-demographic data of the 2011 census of Germany, available via the Statistisches Bundesamt (2019) (Supplementary Table 1). Age, gender, and income of the subsample of the Gesis Panel correspond with the distribution and mean of the German general population. The German statistics of 2011 show a higher proportion of people with a secondary education or lower, and a lower proportion of people with a vocational or tertiary degree than the Gesis Panel sample. Hence, it can be assumed that the sample analyzed is generally representative of the German population, even if slightly better educated.

As outlined in the previously discussed literature, an individual's opinion on climate change can be influenced by socio-demographic variables such as gender, education, personal income, and political identity. These variables have been included in the analysis as control variables (Supplementary Table 3). While the distance of the respondent's residence to the next city is not a variable commonly used in comparable literature, it was also included on the basis that rural and urban populations might have differing experiences with, and dependencies on, weather and climate.

Individual concern about climate change and willingness to mitigate climate change is deduced from the third survey wave of the year, collected each July. The respondents are asked to rate their evaluation to the question "In your opinion, how serious is the problem of climate change currently?" on a scale from zero to ten (Kolb and Weyandt, 2018). Climate change concern increased around 3% from the total average of 8.12–8.41 between 2014 and 2018 on an 11-level scale (Fig. 1a). In 2015 one third of respondents showed stable positions on climate change concern, while one third each exhibited declining and rising concerns compared to their previous year responses (Fig. 1b). By 2018 the share of respondents with stable positions rose to 39%, with

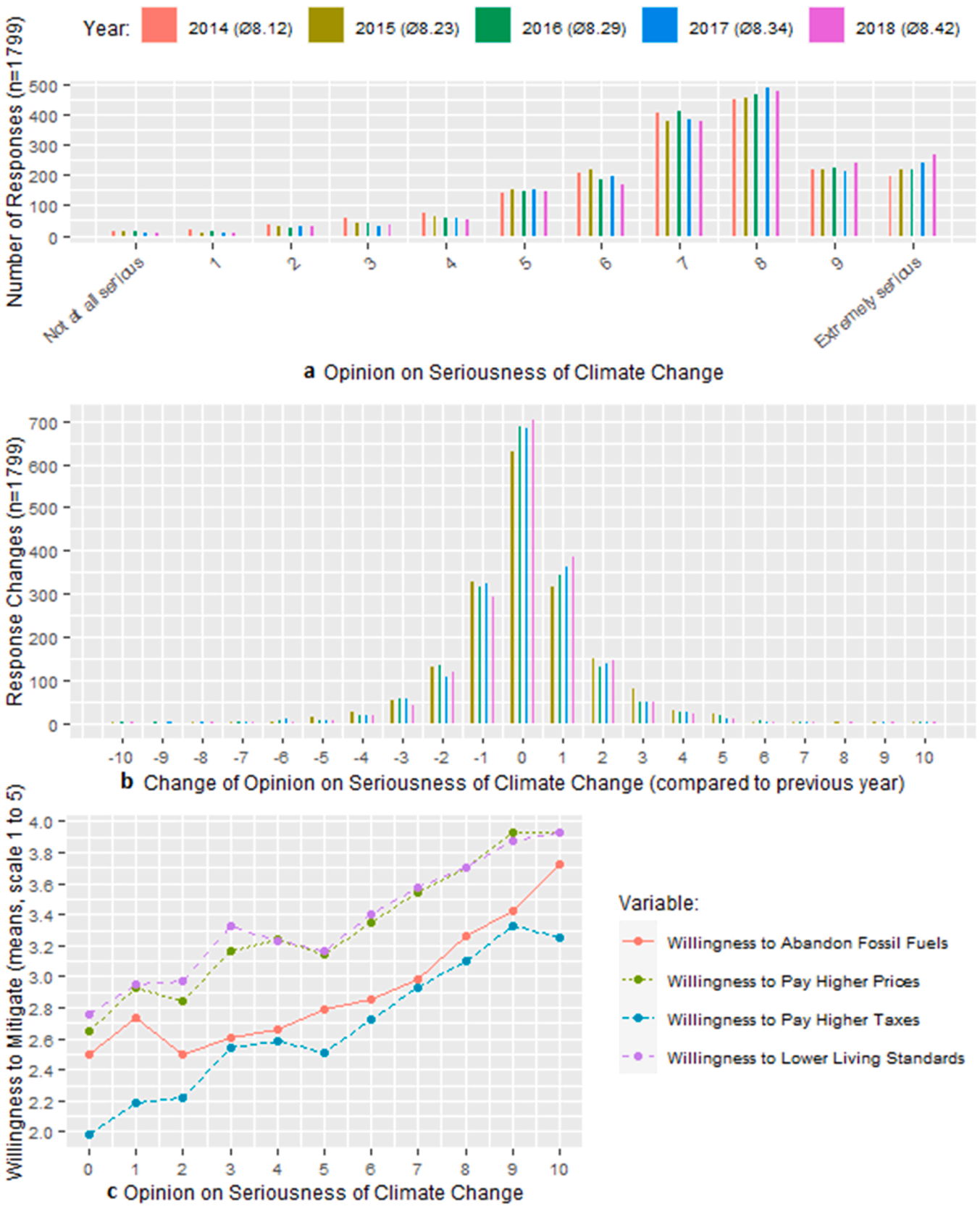

Fig. 1. Distribution of Opinion on Seriousness of Climate Change and Willingness to Mitigate Climate Change in Germany 2014–2018 (Panel a describes the distribution of climate change concern in Germany between 2014 and 2018 on a 11-level scale from not serious at all to extremely serious. The means are displayed next to the respective year in the legend. Panel b shows the variation of this opinion per respondent compared to the previous year. Panel c displays the relationship between the expressed level of climate change concern and the means of the willingness to mitigate indicators).

fewer people feeling a decline in their concern.

The respondents' willingness to mitigate climate change is deduced from their agreement to (1) abandon fossil fuels as soon as possible, (2) pay much higher prices, (3) pay much higher taxes and (4) accept cuts in their standard of living in order to protect the environment on a scale from one to five (Kolb and Weyandt, 2018). While the consent to these measures is less pronounced than the concern about climate change, the increase of the mean of the distribution between 2014 and 2018 is similar and corresponds with the extent of climate change perception (Fig. 1c). While self-determined mitigation options surveyed are on average equally agreed upon (means for prices and living standard: 3.6), governmental solutions, such as taxes (mean: 3.0) and phasing out fossil fuels (mean: 3.1) are less popular. The willingness to abandon fossil fuels was chosen as the final indicator of willingness to mitigate climate change for the regression analysis, due to its clear climate policy association.

3.2. Observed Seasonal Temperature Change

The observed weather data is extracted from a weather and climate dataset available at the Potsdam Institute of Climate Impact Research (PIK) and is an interpolation of weather and climate observations of the weather stations of the Deutscher Wetterdienst (Potsdam Institute for Climate Impact Research, 2019). The timeframe of the data ranges from 2000 to 2018 and post code is its smallest geographical unit.

In a pre-study, the effects of an array of weather and climate variables, including number of snow, heat and storm days, length of longest heat period, and seasonal averages of temperature and precipitation, on the proposed dependent variables were tested. Changes in temperature, however, proved to have the most pronounced and significant effect on individual concern about climate change, and willingness to mitigate, and therefore was analyzed in closer detail.

The resulting analysis chose to investigate the effects of seasonal temperature change. Hence, the recorded temperature for each period was compared to the temperature of the previous year and the 19-year average for each post code area. Inclusion of an analysis of the deviation from the 30-year average was contemplated, but 30-year averages were only available on a municipality level, which was not considered detailed enough. To test temperature deviations experienced as close to the collection date of the social data in July, seasons were defined as the averages of the following months, (1) winter: January, February, March (2) spring: April, May, June (3) summer: July, August, September and (4) fall: October, November, December.

All temperature deviations were calculated in relative (positive or negative change), as well as absolute (extend of change), terms. Seasonal temperature change compared to the previous year proved to have the most significant and largest effect, hence comparisons to the 19-year average are not further discussed (Supplementary Table 7).

Fig. 2 shows the distribution and extent of seasonal temperature deviation in the post code areas compared to the previous year. The temperature deviations ranged from − 3.6–6.1 degrees Celsius and seasonal temperature averages increased by 0.4 degrees Celsius on average during this time frame (Supplementary Table 4). Compared to the 19-year average, seasonal average temperatures fluctuated between 2.1 and 3.2 degrees Celsius and increased on average by 0.6 degree Celsius (Supplementary Table 5).

Fig. 2. Distribution of seasonal temperature change by postal code area in Germany (The matrix displays the counts and extend of variation of relative seasonal temperature compared to the previous year for each respective season and year between 2014 and 2018 for each interpolated postal code area).

4. Method

We present effects estimated with a mixed-effects linear regression based on restricted maximum likelihood (REML). The goal of the analysis is the estimation of the regression parameters β that maximize the log-likelihood function:

$$\max_{b} \sum_{i=1}^{n} \log f(y_i|x_i, b) \quad (1)$$

where y is the dependent and x the explanatory variable and b the dummy argument for the maximization problem. Different model designs were tested, and the best fitting model was selected for this analysis (Supplementary Table 6).

For the regression analysis the place of residence in 2014 is used under the assumption that there was no migration of the respondents, and the unit of post code is considered to be sufficiently small to conduct an analysis at an individual level. Since the panel data is collected in July, summer and fall temperature variabilities of each year are correlated with the opinion collected the following year.

5. Research results

Table 1 displays the results of the mixed-effects logistic regressions for the dependent variable reflecting each individual's concern about climate change, with seasonal temperature variabilities compared to the previous year. The seasonal temperature change variables only become significant when analyzed at an absolute level, i.e. when the direction of the temperature deviation is ignored. All variables, except absolute fall temperature change show a small but significant effect on concern about climate change. All control variables, except level of education and personal income, have significant effects on concern about climate change. The year in which the opinion was recorded has been included in the regression model to control for unobserved events or trends in each year that are common for all individuals (e.g., media coverage, Climate Strikes, Fridays for Future). These unobserved trends become more significant and increase in effect between 2015 and 2018 (compared to the base year in 2014) and have sometimes even the strongest positive effect on concern about climate change by 2018.

The results of the mixed-effects logistic regressions for the dependent variable, reflecting willingness to mitigate climate change, behave in a similar manner. However, apart from fall temperature change, they

Table 1
Effects of seasonal temperature change on concern about climate change (The table displays the fixed effects estimates, standard error and t-values of eight mixed-effect logistic regression models, varying in season and absolute and relative temperature values used. A two-tailed t-test was used to calculate significance levels of the parameters. With the degree of freedom of 1798 the critical t-values for significance levels 0.001, 0.01, 0.05 and 0.10 are 3.296, 2.579, 1.961 and 1.645. *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$,. $p < 0.1$).

	Winter								Spring							
	Relative Variation				Absolut Variation				Relative Variation				Absolut Variation			
	β	Std. Error	t-value		β	Std. Error	t-value		β	Std. Error	t-value		β	Std. Error	t-value	
(Intercept)	7.537	0.306	24.609	***	7.359	0.303	24.308	***	7.516	0.293	25.635	***	7.505	0.293	25.618	***
Temperature	-0.023	0.049	-0.478		0.076	0.043	1.769	.	-0.041	0.027	-1.547		-0.053	0.023	-2.326	*
Distance to City	-0.042	0.025	-1.670	.	-0.040	0.025	-1.615		-0.042	0.025	-1.673	.	-0.042	0.025	-1.684	.
Female	0.387	0.084	4.598	***	0.386	0.084	4.585	***	0.388	0.084	4.603	***	0.388	0.084	4.608	***
Level of Education	0.094	0.072	1.311		0.094	0.072	1.309		0.094	0.072	1.307		0.094	0.072	1.309	
Personal Income	0.001	0.035	0.039		0.001	0.035	0.030		0.002	0.035	0.045		0.002	0.035	0.043	
Political Interest	0.196	0.046	4.263	***	0.196	0.046	4.264	***	0.196	0.046	4.264	***	0.197	0.046	4.289	***
Left-Right Orientation	-0.150	0.019	-7.891	***	-0.150	0.019	-7.900	***	-0.150	0.019	-7.886	***	-0.150	0.019	-7.903	***
Year (compared to 2014)																
year2015	0.055	0.141	0.391		0.247	0.083	2.984	**	0.044	0.064	0.678		0.083	0.044	1.870	.
year2016	0.130	0.100	1.303		0.363	0.115	3.159	**	0.143	0.046	3.147	**	0.134	0.045	3.010	**
year2017	0.175	0.107	1.635		0.416	0.117	3.545	***	0.188	0.047	4.037	***	0.169	0.047	3.601	***
year2018	0.270	0.126	2.134	*	0.489	0.101	4.857	***	0.357	0.046	7.827	***	0.390	0.049	7.888	***
	Summer								**Fall**							
	Relative Variation				Absolut Variation				Relative Variation				Absolut Variation			
	β	**Std. Error**	**t-value**		**β**	**Std. Error**	**t-value**		**β**	**Std. Error**	**t-value**		**β**	**Std. Error**	**t-value**	
(Intercept)	7.473	0.294	25.398	***	7.471	0.293	25.496	***	7.333	0.381	19.256	***	7.275	0.372	19.573	***
Temperature	0.019	0.025	0.761		0.038	0.020	1.935	.	-0.085	0.127	-0.665		0.111	0.116	0.960	
Distance to City	-0.042	0.025	-1.670	.	-0.042	0.025	-1.700	.	-0.042	0.025	-1.666	.	-0.041	0.025	-1.654	.
Female	0.387	0.084	4.599	***	0.386	0.084	4.588	***	0.387	0.084	4.599	***	0.388	0.084	4.601	***
Level of Education	0.094	0.072	1.309		0.094	0.072	1.314		0.094	0.072	1.307		0.094	0.072	1.308	
Personal Income	0.001	0.035	0.040		0.001	0.035	0.015		0.001	0.035	0.038		0.001	0.035	0.037	
Political Interest	0.196	0.046	4.263	***	0.196	0.046	4.265	***	0.197	0.046	4.269	***	0.197	0.046	4.274	***
Left-Right Orientation	-0.150	0.019	-7.890	***	-0.150	0.019	-7.905	***	-0.150	0.019	-7.892	***	-0.150	0.019	-7.895	***
Year (compared to 2014)																
year2015	0.149	0.056	2.653	**	0.180	0.051	3.491	***	0.335	0.325	1.029		0.406	0.301	1.349	
year2016	0.185	0.044	4.198	***	0.204	0.044	4.615	***	0.382	0.317	1.206		0.466	0.308	1.513	
year2017	0.242	0.049	4.942	***	0.282	0.052	5.456	***	0.379	0.240	1.577		0.461	0.253	1.825	.
year2018	0.375	0.076	4.924	***	0.329	0.041	7.977	***	0.552	0.342	1.615		0.596	0.283	2.102	*

show weaker effects and show lower significance levels than the results of the climate change concern models (Supplementary Table 8 and 9). The spring and fall temperature change variables also only show significant effects on willingness to mitigate when analyzed at an absolute level, while summer and winter temperature change do not prove to be significant at all. All control variables, except level of education and personal income, have significant effects on willingness to mitigate. The unobserved trends, captured in the year variable, also become more significant and increase in effect between 2015 and 2018 (compared to the base year in 2014) and have the strongest positive effect on willingness to mitigate by 2018.

The percentage effect and standard deviation for each variable of concern about climate change is displayed in Fig. 3. Except for the level of education and personal income, socio-demographic variables have the largest effects on concern about climate change. Being female increased the level of concern by 4.26%. Opinion on the seriousness of climate change increases by 2.16% per unit of additional political interest expressed by the respondents (on a scale from 1-weak to 5-strong). Concern about climate change decreased by 1.65% per unit to the right that respondents identified on a left to right political orientation spectrum (11 levels). An individual's geographic distance to a city also significantly influenced concern about climate change: with each level of increasing distance to a city (6 levels) there was a decrease of 0.46% in the opinion on the seriousness of climate change. Across the absolute seasonal temperature change, varying winter temperature showed the largest effect on opinions. With each degree Celsius deviation of the winter average temperature from the previous year, concern about climate change increased by 0.83%. Summer temperature change had a similar, but smaller, effect, increasing concern by 0.42%. Spring temperature change is negatively correlated with concern about climate change, showing reductions of 0.59% per degree Celsius. Unlike the effects of the socio-demographic variables, the effects of the unobserved trends captured in the year variable, differ between the seasonal datasets analyzed. Therefore, the effects specific to the summer temperature variation are displayed in Fig. 4. Here it becomes apparent that concern about climate change increases every year driven by common unobserved drivers. Compared to 2014, these unobserved drivers have the effect of increasing concern about climate change by almost 3%.

The percentage effect and standard deviation for each variable on willingness to mitigate climate change is displayed in Fig. 5, with the effects of the socio-demographic variables again described in a generalized manner across all models. Except for the level of education and personal income, socio-demographic variables have the most significant effects on willingness to mitigate climate change, albeit slightly lower than on climate change concern. Being female increases willingness to mitigate by 2%. Willingness to abandon fossil fuels increases by 1.83% per unit of additional political interest expressed by the respondents (on a scale from 1-weak to 5-strong). Willingness to mitigate climate change decreased by 1.52% per unit to the right that respondents identified on a left to right political orientation spectrum (11 levels). With each level of increasing distance to a city (6 levels) willingness to mitigate climate change decreases by 0.55%, which is slightly higher than its effect on climate change concern. Across the absolute seasonal temperature change, varying temperature in the fall showed the largest effect. With each degree Celsius the average temperature in the fall deviated from the previous year, willingness to abandon fossil fuels increased by 2.05%. Spring temperature change is negatively correlated with willingness to mitigate, with a reduction of 0.49% per degree Celsius.

Considering the maximum values of the continuous temperature variables and the number of levels of the categorical socio-demographic variables, Table 2 presents the maximum effect predicted for each variable on concern about climate change and willingness to mitigate climate change, respectively. These values clearly show the magnitude of the effect that socio-demographic variables have as compared to seasonal temperature changes. Hence, a person who holds far-left political views is likely to express a 16.5% higher concern for climate change and a 15.2% higher willingness to mitigate climate change than a person who holds far-right political views. In comparison, a person experiencing the maximum observed seasonal temperature variation is likely to express concern about climate change that is 1.3% (summer) to 5.0% (winter) higher as compared to persons who do not experience temperature variation. Similarly, a person who experiences the maximum observed seasonal temperature variation is likely to express a variable amount of willingness to mitigate climate change that ranges from − 1.53% (spring) to 7.32% (fall) as compared to persons who do not experience this temperature variation.

6. Discussion and conclusions

The results of this study show that seasonal temperature change influences personal climate change concerns even in temperate climate zones. While relative variations and temperatures in the fall did not prove to have significant effects, absolute winter and summer temperature change show positive effects. Spring temperature change has significant negative effects on climate change concern. Additionally, although the effects of relative temperature change are not statistically

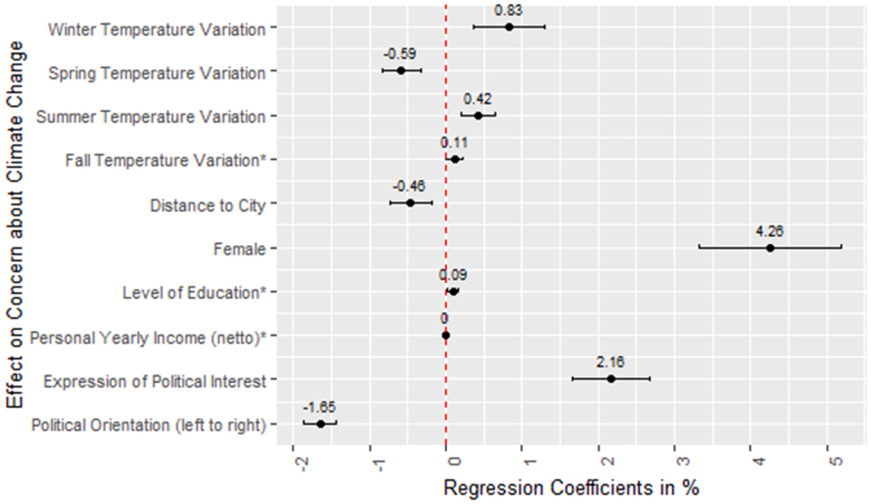

Fig. 3. Effects in % for concern about climate change and absolute seasonal temperature deviation from previous year (The Figure shows consolidated regression coefficients standardised in %. Socio-demographic variables: similar across seasonal temperature datasets, hence only results of the summer model are displayed. The standard deviation is displayed in the error bars. Non-significant variables are marked with *).

Fig. 4. Effects in % for concern about climate change and absolute summer temperature deviation from previous year (The Figure shows regression coefficients standardised in %. The standard deviation is displayed in the error bars. Non-significant variables are marked with *).

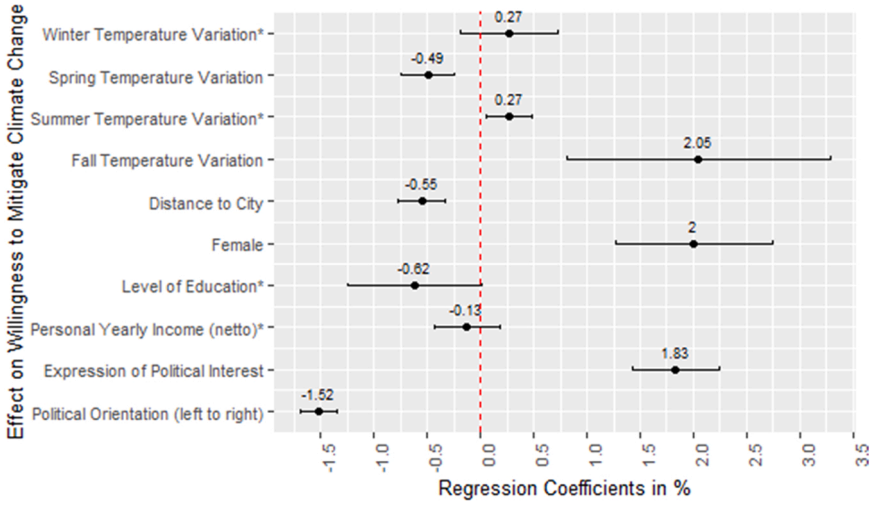

Fig. 5. Effects in % for willingness to mitigate climate change and absolute seasonal temperature deviation from previous year (The Figure shows consolidated regression coefficients standardised in %. Socio-demographic variables: similar across seasonal temperature datasets, hence only results of the summer model are displayed. The standard deviation is displayed in the error bars. Non-significant variables are marked with *).

significant, absolute change has considerably larger effects. This indicates that it is more important that seasonal temperatures are experienced as "different to usual" than whether it gets colder or warmer.

While the effects of temperature change on willingness to mitigate are less robust than on climate change concern, spring and fall temperature variation show significant effects. Additionally, the responses to the support of mitigation measures correspond with the extent of each individual's climate change perception (Fig. 1c). Hence the effects of seasonal temperature change on concern about climate change may offer a window of opportunity for more stringent climate change policy. Furthermore, the stronger results for the summer seasons may indicate that these effects may be stronger when the experience of seasonal temperature change is conceptualized as an effect of climate change. Therefore, enhancing the communication of this relationship opens a second window of opportunity to increase public support of mitigation measures.

This communication could be targeted toward altering the mental models that people use to interpret their environment, retrieve memorized information, and apply this knowledge to problem solving (Denzau and North, 1994; Otto-Banaszak et al., 2011). Mental models are flexible and manipulable (Senge, 1990), and they can be corrected for flaws or uncertainties, which cause unpredicted events. Therefore, they are seen as drivers for learning and action. Issuing such communications during unusual temperature changes, informing people that climate change is occurring here and now, and advocating specific climate adaptations and mitigation measures can help alter the current mental models, facilitate learning and promote collective action.

Furthermore, the results suggest that respondents are more likely to accept self-determined mitigation options, such as lowering living standards and paying higher prices, while governmental solutions such as taxes and phasing out of fossil fuels showed to be less supported.

The positive effects of winter, summer and fall temperature change on climate change perceptions were expected and are in accordance with previous studies identifying positive effects of local temperature change on climate change perception (Egan and Mullin, 2012; Howe, 2018). However, the decreasing significant effect of absolute spring temperature variation is surprising and may be explained by several factors. Spring average temperatures increased between 2014 and 2018 (Fig. 2; Supplementary Table 4 and 5) and the milder seasons may have been welcomed and considered as positive. Furthermore spring

Table 2
Maximum predicted effects in % on concern about climate change and willingness to mitigate climate change.

Variable	Max. predicted effect on concern about climate change in %	Max. predicted effect on willingness to mitigate climate change in %
Winter temperature variation	5.01	n.a.
Spring temperature variation	-1.85	-1.53
Summer temperature variation	1.26	n.a.
Fall temperature variation	n.a.	7.32
Distance to city	-2.30	-2.75
Female	4.26	2.00
Expression of political Interest	8.64	7.32
Political orientation (left - right)	-16.50	-15.20

temperatures have been linked less with climate change in the media than temperature in other seasons (Lang, 2014). The small and insignificant effect of fall temperature change also underlines the possibility that the extreme seasons of summer and winter are more widely recognized as being influenced by climate change, with decreasing snow days and increasing heat days being experienced.

While the individual experience of temperature change in summer had a smaller effect on climate change concern than in winter, one must bear in mind that broader societal changes have been captured in the annual variables. The increasing significance and effect of broader societal changes in recent years (compared to 2014) indicate that climate change concern intensifies over time, particularly in the spring and summer models. This trend is likely to be a combination of shared experience of warmer springs and summers, the increased attention to climate change in media and politics, and rise in visibility of climate activism (e.g., through the Fridays for Future movement). Hence the increasing concern for climate change is influenced by such broader societal changes as well as the individual experience of seasonal temperature change. With warmer summers and linked heat waves being widely discussed in the media as effects of climate change they are likely to be perceived as a common trend, even leading to the term "Heisszeit" ("Heat Age"; adaptation of the term of Ice Age) being voted German *Word of the Year* in 2018 (GfdS, 2018). Winter temperature variations, however, have been less discussed in connection with climate change and are therefore more likely to be captured in the model as an individual experience. This emphasizes the necessity to understand how people conceptualize climate change, as many studies suggest that perceptions are only affected by events associated with climate change (Borick and Rabe, 2017).

The calculated maximum predicted effects of the independent variables in Table 2 show the extent and limitations of each variable's effect on people's concern about climate change and their willingness to mitigate. It also highlights the possible effects when examining the extremes, e.g. comparing people with far-left and far-right political views or comparing no temperature change to a maximum temperature change of 6 degrees Celsius. While the regression coefficients for seasonal temperature variables are considerably small, people who experience extreme temperature changes in winter and fall may express more concern about climate change or willingness to mitigate, based on factors like their gender or expression of political interest. Apart from their political views, these effects are rather small – even for the extremes – ranging from 1.53% to 8.6%. This means that each of these effects constitutes a contributing rather than a leading factor in shaping a person's concern about climate change and their willingness to mitigate.

We argue that changing local climate and weather conditions have a potential to sensitize people to climate change and can offer the opportunity to implement policies leading to large scale social change towards decarbonisation. Research on social tipping dynamics suggests that even small interventions can lead to drastic social change through so-called "contagious spreading (…) of behaviors, opinion, knowledge, technologies or social norms" (Otto et al., 2020). Understanding when the public is most open to policy interventions can speed up policy implementation. By identifying the possibility of such windows of opportunity, policy makers can prepare strategies and implement policy when they are most likely to be supported by the public.

Unlike previous studies, personal income (Akerlof et al., 2013; Myers et al., 2012) and education (Akerlof et al., 2013; Borick and Rabe, 2014; Egan and Mullin, 2012; Hamilton and Stampone, 2013; Myers et al., 2012) had no statistically significant effect on climate change concern and willingness to mitigate in Germany. The bilinear shape of the correlation curve between expression of political interest and concern about climate change (see Supplementary Figure 3) indicates that higher degree of political interest can either have a strong increasing or decreasing effect on the responses, meaning that the effect is probably higher when splitting the sample in respondents of low and high concern for climate change. In general, this identified trend is consistent with research in the USA where the degree of party affiliation behaves in a similar manner (Borick and Rabe, 2014). Identifying further to the right on a left to right political spectrum, decreases respondent's opinion on seriousness of climate change and willingness to mitigate by approximately 1.52–1.65% per level. Political orientation is a good indicator how group affiliation and a corresponding mental model possibly influences personal opinion and has produced similar effects for party affiliation in the USA (Marquart-Pyatt et al., 2014; Ray et al., 2017). All parties represented in the German Parliament, except for the far-right AFD party, positioned climate protection at the core of their election program during the 2021 German federal elections (Welle, 2021). This trend of climate change protection being moved more and more into the political mainstream may help to detach climate change concern from the far-left political identity and lead to more changes in concern about climate change among conservative voters.

Living further away from a city has a decreasing effect on both dependent variables. This variable was categorized in 6 uneven levels of approximately 10–20 km, hence approximately each additional 15 km of distance between residence and a city decreased concern about climate change and willingness to mitigate by approximately half a percent. Janko et al. (2018) found similar trends in the Hungarian population were the size of settlements of the respondent's residence positively influenced concern about climate change and willingness to act. Declining trends with increasing distance to cities might to some extend be explained by its strong link to political ideology. Since the impacts of weather and climate variations are however experienced differently in rural compared to urban areas, a split sample analysis might offer some new information.

The high and statistically significant effects of the socio-demographic variables may indicate that there are different clusters of respondents that need to be addressed differently. Climate change communication, targeting different citizen groups, is important to enhance the effects of the experience of changing climate and weather on climate change opinion, since the reception of a message is not only highly dependent on experiences but also prior beliefs (Borick and Rabe, 2017). In our sample, opinions of respondents identifying further to the political right or in higher income groups tended to vary the most. Metag et al. (2017) identified five different typologies of Germans' views on climate change and patterns of media use. In particular, people who are disengaged or doubtful about the existence of climate change barely seek information on this matter. While the disengaged avoid information-oriented and complex reporting in favor of tabloids, the doubtful seek their information online. Interestingly, television is used as an information source across all typologies (Metag et al., 2017). Communicating intangible

bridges between climate change and resulting changes in weather and seasonal climate in local mainstream media - for example in the weather forecast - may have enhancing effects.

Even with increasing climate change concern and willingness to mitigate, one needs to be aware of barriers for these perceptions to translate to real action for climate protection. Next to socio-demographics, and awareness building experiences and communication discussed in our study, particularly perceived costs play an important role in motivating or hindering action (Kollmuss and Agyeman, 2002; Diekmann and Preisendörfer, 2003).

Our findings differ to the similar study of Gärtner and Schoen (2021). While they were not able to confirm effects of extreme weather conditions on climate change perceptions in Germany, our study was able to identify small but significant effects of seasonal temperature change. We believe that this is due to the character of the weather conditions we looked at. Germany is located in the temperate climate zone and it has so far suffered a lower magnitude of weather extremes and climate change impacts than other world regions. We suppose this explains why the authors, despite applying several different models did not find significant effects of experiencing weather extremes on perceptions of climate change and climate policy attitudes (Gärtner and Schoen, 2021). In contrast, we looked at seasonal temperature changes, that turned out to have a significant influence on perceptions of climate change and climate change policy attitudes. Similar to the study of Gärtner and Schoen (2021), we also applied a mixed-effect linear regression to capture interdependencies, hence the significant effects of our study cannot be attributed to an overestimation. Both studies used the same source of weather data, and similar panel data, time frame and resolution. Our differing results therefore indicate that rather than the experience of short lasting and sudden weather extremes, which are still rare in the studied climate zone compared to other world regions, longer timeframes of temperature abnormalities can shape climate change perception and willingness to mitigate in Germany. This contradicts the common consensus that citizens predominantly shape their risk perception based on temporal close events and adds to the growing understanding that also long term and subtle changes can influence citizens' mental models and consequently lead to shifts in attitudes and responses (cf. Otto-Banaszak et al., 2011; Otto et al., 2020).

In our study, time and access restrictions on the use of the data in the Gesis security data center limited the possibility of further model development and additional evaluation. The rich data treasure of the longitudinal data collection used in combination with observational weather data, however, has potential for further exploration, particularly in the analysis of typologies and clusters within the German population and the development of climate change perceptions. While in the overall sample the level of education and personal income had no significant effect, they may be influential in clustered population groups.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

The authors do not have permission to share data.

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CRediT authorship contribution statement

Lena Pfeifer: Conceptualization; Methodology; Validation; Formal analysis; Writing - Original Draft, Review & Editing; Visualization; **Ilona M. Otto:** Conceptualization; Writing - Original Draft, Review & Editing.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.envsci.2022.11.010.

References

Potsdam Institute for Climate Impact Research, 2019. Interpolation of Weather Data 2013 to 2018. Potsdam Institute for Climate Impact Research, Potsdam.
Agnone, J., 2007. Amplifying Public Opinion: The Policy Impact of the U.S. Environmental Movement. Soc. Forces 85, 1593–1620. https://doi.org/10.1353/sof.2007.0059.
Akerlof, K., Maibach, E.W., Fitzgerald, D., Cedeno, A.Y., Neuman, A., 2013. Do people "personally experience" global warming, and if so how, and does it matter? Glob. Environ. Change 23, 81–91. https://doi.org/10.1016/j.gloenvcha.2012.07.006.
Borick, C.P., Rabe, B.G., 2014. Weather or Not? Examining the Impact of Meteorological Conditions on Public Opinion regarding Global Warming. Weather Clim. Soc. 6, 413–424. https://doi.org/10.1175/WCAS-D-13-00042.1.
Borick, C.P., Rabe, B.G., 2017. Personal Experience, Extreme Weather Events, and Perceptions of Climate Change. Oxford University Press,. ⟨https://doi.org/10.1093/acrefore/9780190228620.013.311⟩.
Burns, T.R., 1994. Two conceptions of agency: Rational choice theory and the social theory of action.
Cremades, R., Surminski, S., Máñez Costa, M., Hudson, P., Shrivastava, P., Gascoigne, J., 2018. Using the adaptive cycle in climate-risk insurance to design resilient futures. Nat. Clim. Change 8, 4–7. https://doi.org/10.1038/s41558-017-0044-2.
Demski, C., Capstick, S., Pidgeon, N., Sposato, R.G., Spence, A., 2017. Experience of extreme weather affects climate change mitigation and adaptation responses. Clim. Change 140, 149–164. https://doi.org/10.1007/s10584-016-1837-4.
Denzau, A.T., North, D.C., 1994. Shared Mental Models: Ideologies and Institutions. Kyklos 47, 3–31. https://doi.org/10.1111/j.1467-6435.1994.tb02246.x.
Deutsche Welle, 2021. German election: Is this the climate election, or isn't it? | DW | 17.09.2021. DW.COM. ⟨https://www.dw.com/en/german-election-is-this-the-climate-election-or-isnt-it/a-59210865⟩.
Diamond, E., Bernauer, T., Mayer, F., 2020. Does providing scientific information affect climate change and GMO policy preferences of the mass public? Insights from survey experiments in Germany and the United States. Environ. Polit. 29 (7), 1199–1218. https://doi.org/10.1080/09644016.2020.1740547.
Diekmann, A., Preisendörfer, P., 2003. Green and Greenback: The Behavioral Effects of Environmental Attitudes in Low-Cost and High-Cost Situations. Ration. Soc. 15 (4), 441–472. https://doi.org/10.1177/1043463103154002.
Donner, S.D., McDaniels, J., 2013. The influence of national temperature fluctuations on opinions about climate change in the U.S. since 1990. Clim. Change 118, 537–550. https://doi.org/10.1007/s10584-012-0690-3.
Egan, P.J., Mullin, M., 2012. Turning Personal Experience into Political Attitudes: The Effect of Local Weather on Americans' Perceptions about Global Warming. J. Polit. 74, 796–809. https://doi.org/10.1017/S0022381612000448.
Engels, A., Hüther, O., Schäfer, M., Held, H., 2013. Public climate-change skepticism, energy preferences and political participation. Glob. Environ. Change 23 (5), 1018–1027. https://doi.org/10.1016/j.gloenvcha.2013.05.008.
Gärtner, L., Schoen, H., 2021. Experiencing climate change: revisiting the role of local weather in affecting climate change awareness and related policy preferences. Clim. Change 167, 31. https://doi.org/10.1007/s10584-021-03176-z.
GESIS, 2018. GESIS - Leibniz Institute for the Social Sciences [WWW Document]. URL ⟨https://www.gesis.org/en/institute/⟩ (accessed 2.26.19).
GESIS, 2019. GESIS Panel - Extended Edition. ⟨https://doi.org/10.4232/1.12972⟩.
GfdS, 2018. GfdS wählt "Heißzeit" zum Wort des Jahres 2018 [WWW Document]. URL ⟨https://gfds.de/wort-des-jahres-2018/⟩ (accessed 3.13.19).
Hamilton, L.C., Stampone, M.D., 2013. Blowin' in the Wind: Short-Term Weather and Belief in Anthropogenic Climate Change. Weather Clim. Soc. 5, 112–119. https://doi.org/10.1175/WCAS-D-12-00048.1.
Hart, P.S., Nisbet, E.C., 2012. Boomerang effects in science communication: How motivated reasoning and identity cues amplify opinion polarization about climate mitigation policies: (578192014–270). ⟨https://doi.org/10.1037/e578192014–270⟩.

Howe, P.D., 2018. Perceptions of seasonal weather are linked to beliefs about global climate change: evidence from Norway. Clim. Change 148, 467–480. https://doi.org/10.1007/s10584-018-2210-6.
IEA, 2022. Global Energy Review: CO2 Emissions in 2021. IEA. ⟨https://www.iea.org/reports/global-energy-review-co2-emissions-in-2021–2⟩.
Janko, F., Bertalan, L., Hoschek, M., Nemeth, N., Papp-Vansco, J., 2018. Perception, understanding, and action: attitudes of climate change in the Hungarian population 14.
Kolb, J.-P., Weyandt, K., 2018. GESIS Panel Incremental Codebook.
Kollmuss, A., Agyeman, J., 2002. Mind the Gap: Why do people act environmentally and what are the barriers to pro-environmental behavior. Environ. Educ. Res. 8 (3), 239–260. https://doi.org/10.1080/13504620220145401.
Kreibich, H., 2011. Do perceptions of climate change influence precautionary measures? Int. J. Clim. Change Strateg. Manag. 3, 189–199. https://doi.org/10.1108/17568691111129011.
Kundzewicz, Z.W., Matczak, P., Otto, I.M., Otto, P.E., 2020. From "atmosfear" to climate action. Environ. Sci. Policy 105, 75–83. https://doi.org/10.1016/j.envsci.2019.12.012.
Lang, C., 2014. Do weather fluctuations cause people to seek information about climate change. Clim. Change 125, 291–303. https://doi.org/10.1007/s10584-014-1180-6.
Leviston, Z., Price, J., Bishop, B., 2014. Imagining climate change: The role of implicit associations and affective psychological distancing in climate change responses. Eur. J. Soc. Psychol. 44, 441–454. https://doi.org/10.1002/ejsp.2050.
Li, Y., Johnson, E.J., Zaval, L., 2011. Local Warming: Daily Temperature Change Influences Belief in Global Warming. Psychol. Sci. 22, 454–459. https://doi.org/10.1177/0956797611400913.
Marquart-Pyatt, S.T., McCright, A.M., Dietz, T., Dunlap, R.E., 2014. Politics eclipses climate extremes for climate change perceptions. Glob. Environ. Change 29, 246–257. https://doi.org/10.1016/j.gloenvcha.2014.10.004.
McDonald, R.I., Chai, H.Y., Newell, B.R., 2015. Personal experience and the 'psychological distance' of climate change: An integrative review. J. Environ. Psychol 44, 109–118. https://doi.org/10.1016/j.jenvp.2015.10.003.
Metag, J., Füchslin, T., Schäfer, M.S., 2017. Global warming's five Germanys: A typology of Germans' views on climate change and patterns of media use and information. Public Underst. Sci. 26, 434–451. https://doi.org/10.1177/0963662515592558.
Myers, T.A., Maibach, E.W., Roser-Renouf, C., Akerlof, K., Leiserowitz, A.A., 2012. The relationship between personal experience and belief in the reality of global warming. Nat. Clim. Change 3, 343–347. https://doi.org/10.1038/nclimate1754.
Otto, I.M., Donges, J.F., Cremades, R., Bhowmik, A., Hewitt, R.J., Lucht, W., Rockström, J., Allerberger, F., McCaffrey, M., Doe, S.S.P., Lenferna, A., Morán, N., van Vuuren, D.P., Schellnhuber, H.J., 2020. Social tipping dynamics for stabilizing Earth's climate by 2050. Proc. Natl. Acad. Sci. 117, 2354–2365. https://doi.org/10.1073/pnas.1900577117.
Otto-Banaszak, I., Matczak, P., Wesseler, J., Wechsung, F., 2011. Different perceptions of adaptation to climate change: a mental model approach applied to the evidence from expert interviews. Reg. Environ. Change 11, 217–228. https://doi.org/10.1007/s10113-010-0144-2.
Ray, A., Hughes, L., Konisky, D.M., Kaylor, C., 2017. Extreme weather exposure and support for climate change adaptation. Glob. Environ. Change 46, 104–113. https://doi.org/10.1016/j.gloenvcha.2017.07.002.
Renn, O., Marshall, J.P., 2016. Coal, nuclear and renewable energy policies in Germany: From the 1950s to the "Energiewende. Energy Policy 99, 224–232. https://doi.org/10.1016/j.enpol.2016.05.004.
Reser, J.P., Bradley, G.L., Ellul, M.C., 2014. Encountering climate change: 'seeing' is more than 'believing': 'Seeing' is more than 'believing. Wiley Interdiscip. Rev. Clim. Change 5, 521–537. https://doi.org/10.1002/wcc.286.
Schäfer, M., Jaeger-Erben, M., Bamberg, S., 2012. Life Events as Windows of Opportunity for Changing Towards Sustainable Consumption Patterns?: Results from an Intervention Study. J. Consum. Policy 35, 65–84. https://doi.org/10.1007/s10603-011-9181-6.
Schumpeter, J.A., 2010. Capitalism, Socialism and Democracy, 0 ed..,. Routledge,. ⟨https://doi.org/10.4324/9780203857090⟩.
Senge, P., 1990. The fifth discipline: The an and practice of the learning organization. N. Y. Duubeday Curr.
Shum, R.Y., 2012. Effects of economic recession and local weather on climate change attitudes. Clim. Policy 12, 38–49. https://doi.org/10.1080/14693062.2011.579316.
Singh, A.S., Zwickle, A., Bruskotter, J.T., Wilson, R., 2017. The perceived psychological distance of climate change impacts and its influence on support for adaptation policy. Environ. Sci. Policy 73, 93–99. https://doi.org/10.1016/j.envsci.2017.04.011.
Sisco, M., Bosetti, V., Weber, E., 2017. When do extreme weather events generate attention to climate change. Clim. Change 143, 227–241. https://doi.org/10.1007/s10584-017-1984-2.
Smith, E.K., Eder, C., Katsanidou, A., 2020. On thinning ice: understanding the knowledge, concerns and behaviors towards polar ice loss in Germany. Polar Geogr. 43 (4), 243–258. https://doi.org/10.1080/1088937X.2020.1755904.
Spence, A., Poortinga, W., Pidgeon, N., 2012. The Psychological Distance of Climate Change. Risk Anal. 32, 957–972. https://doi.org/10.1111/j.1539-6924.2011.01695.x.
Spence, A., Poortinga, W., Butler, C., Pidgeon, N.F., 2011. Perceptions of climate change and willingness to save energy related to flood experience. Nat. Clim. Change 1, 46–49. https://doi.org/10.1038/nclimate1059.
Statistisches Bundesamt, 2019. Federal Statistical Office Germany - GENESIS-Online [WWW Document]. URL ⟨https://www-genesis.destatis.de/genesis/online/data;sid=945824E00749A30FA96464E4B55CAF72.GO_2_2?operation=abruftabelleBearbeiten&levelindex=1&levelid=1551954305882&auswahloperation=abruftabelleAuspraegungAuswaehlen&auswahlverzeichnis=ordnungsstruktur&auswahlziel=werteabruf&selectionname=81000–0007&auswahltext=&werteabruf=Value+retrieval⟩ (accessed 3.7.19).
Taylor, A., de Bruin, W.B., Dessai, S., 2014a. Climate Change Beliefs and Perceptions of Weather-Related Changes in the United Kingdom: Climate Change Beliefs. Risk Anal. 34, 1995–2004. https://doi.org/10.1111/risa.12234.
Taylor, A., Dessai, S., Bruine de Bruin, W., 2014b. Public perception of climate risk and adaptation in the UK: A review of the literature. Clim. Risk Manag. 4–5, 1–16. https://doi.org/10.1016/j.crm.2014.09.001.
Verplanken, B., Wood, W., 2006. Interventions to Break and Create Consumer Habits. J. Public Policy Mark. 25, 90–103. https://doi.org/10.1509/jppm.25.1.90.
von Möllendorff, C., Hirschfeld, J., 2016. Measuring impacts of extreme weather events using the life satisfaction approach. Ecol. Econ. 121, 108–116. https://doi.org/10.1016/j.ecolecon.2015.11.013.
Zanocco, C., Boudet, H., Nilson, R., Satein, H., Whitley, H., Flora, J., 2018. Place, proximity, and perceived harm: extreme weather events and views about climate change. Clim. Change. https://doi.org/10.1007/s10584-018-2251-x.
Ziegler, A., 2017. Political orientation, environmental values, and climate change beliefs and attitudes: An empirical cross country analysis. Energy Econ. 63, 144–153. https://doi.org/10.1016/j.eneco.2017.01.022.

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