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Extreme heat experience influences public support for local climate adaptation policies in Germany

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ABSTRACT

Extreme heat events, made more frequent and severe by climate change, are negatively impacting human populations across the world. Understanding how populations are being impacted, especially among the most vulnerable, is therefore a policy imperative. We contribute to this understanding by investigating experiences of Germans following the summer of 2022, a season noteworthy for extreme temperatures throughout Europe. We conducted a survey of German residents ($n = 2356$) and found that a wide majority (85%) reported negative impacts from heat, including difficulty falling asleep, discomfort, and decreased productivity. These impacts occurred more frequently for vulnerable groups, such as the financially insecure. Furthermore, we found that living in areas with more frequent high temperature days (i.e., objective heat experience) corresponded to higher reported impacts from heat. We then identified factors influencing support for local governmental policies related to heat adaptation. We found broad support among those who reported higher levels of heat impacts, with support for some policies, such as subsidizing residential air conditioning, associated with higher objective heat experience. Our research reinforces the urgent need for comprehensive policies that protect Germans from heat, with a focus on the most vulnerable, as heat impacts are projected to only worsen under future warming.

1. Introduction

Heat waves during the summer of 2022 broke high temperature records worldwide, and to date is the hottest summer on record in Europe. These heat events contributed to substantial human loss, resulting in approximately 60,000 deaths in Europe alone, with Italy, Spain and Germany having the most heat-related deaths (Ballester et al., 2023). These unprecedented heat events were linked to human-caused climate change (IPCC, 2022). Europe, in particular, has experienced greater warming due to climate change compared to other continents (van Daalen et al., 2022), and predictions suggest an increase in the magnitude of heat waves across Europe, with the most dramatic rise in Central Europe (Smid et al., 2019). This pattern in Europe joins an alarming trend of changes in the global climate that will increase the frequency and severity of extreme temperature events in future periods (Perkins-Kirkpatrick and Lewis, 2020). Absent of comprehensive climate mitigation and adaptation policies, projected temperature increases will only accelerate

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associated health impacts on populations in Europe as well as globally (Martínez-Solanas et al., 2021).

However, the effects of extreme weather events, fueled by climate change, are not being experienced equally by human populations. Differences in climate, government policies, extreme events exposure as well as many other individual-level factors, ranging from sociodemographics to acclimatization and risk awareness, can all contribute to variation in impacts from extreme events (Adnan et al., 2022; Zander et al., 2017, 2019; Zanocco et al., 2022a). This variation can manifest across regions and countries as well as within countries and by population, with vulnerability to extreme events often having social and economic dimensions (Thomas et al., 2019). For extreme heat events, impacts from heat among vulnerable populations are an ongoing concern. These vulnerable populations might already be facing challenges that are exacerbated by extreme heat while limiting their capacity to protect themselves and other members of their household. Such was the case with compounding hazards related to extreme heat events during the initial stages of the COVID-19 pandemic (Wilhelmi et al., 2021). As Europe warms, the confluence of climate change, urbanization, and an aging population will only make society more exposed and vulnerable to extreme heat events in the future (Brücker, 2005; Smid et al., 2019).

Prior literature has indicated that a variety of personal and household characteristics can lead to higher levels of extreme heat risk. Characteristics commonly associated with heat vulnerability include age, gender, educational attainment, income, health, household size, and race and ethnicity (Cutter et al., 2003; Osberghaus and Abeling, 2022; Park et al., 2020; Schoessow et al., 2022; van Steen et al., 2019). With respect to age, those who are elderly are at greater physiological risk from heat exposure and could also face increased challenges in accessing healthcare. Notably, in the summer of 2022 those 65 or older accounted for 90% of all heat-related deaths in Europe (Smith, 2023). In terms of gender, men have higher rates of heat-related deaths in the United States (Schoessow et al., 2022), but in the summer of 2022 it was women who had a higher risk of mortality in Europe (Ballester et al., 2023). So while gender is shown to be related to increased heat vulnerability, the direction of this relationship is not always consistent. Similarly, household size has also been found to have inconsistent directionality. Some literature has argued that larger households have more access to resources and a lower likelihood of social isolation, while other literature has suggested that larger households may have higher numbers of heat-vulnerable occupants (Schoessow et al., 2022). When examining educational attainment, those with higher educational attainment may have more capacity to protect themselves by understanding or processing information or accessing services (Cutter et al., 2003), similar to those with higher incomes who can more readily acquire and deploy protective resources (K. Ebi et al., 2018). For those who have disabilities or chronic medical conditions, these individuals may face challenges that include a higher likelihood of health impacts related to heat exposure (Ebi et al., 2018).

Recent research about the 2022 European heat events has focused on mortality related to extreme heat (Ballester et al., 2023), joining an extensive and growing body of literature on heat-related health issues (e.g., Ebi et al., 2021; Faurie et al., 2022; Liu et al., 2021; Xu et al., 2016). However, we currently lack an understanding of other, less acute impacts, as well as a more nuanced understanding of how these impacts may manifest. In this respect, we may not be sufficiently capturing everyday negative experiences with heat. For instance, extreme heat can cause sleeping problems (Altena et al., 2023), can reduce work productivity (Szewczyk et al., 2021) and increase the risk of workplace injuries (Kampe et al., 2016), and has been linked with adverse mental health outcomes (Liu et al., 2021). Vulnerability is also affected by the way people perceive themselves to be at risk from extreme heat, which can influence protective behaviors and lead to different impacts even across similarly exposed populations (e.g., older people may underestimate their elevated risk, which can result in less use of heat-protective behaviors) (Hass et al., 2021; Schoessow et al., 2022; Zander et al., 2017). We therefore approach this research inquiry from the perspective of understanding self-reported, or subjective, experiences with heat and how this relates to vulnerable characteristics identified in previous literature (Beckmann and Hiete, 2020; Osberghaus and Abeling, 2022; Schoessow et al., 2022; Zander et al., 2019). The vulnerable characteristics we consider include age (65 or older), gender (male), income (financial difficulties), education (lower educational attainment), health (chronic medical conditions) and household composition (number of occupants). We formalize this in the following hypothesis:

(H1) Those with vulnerable characteristics related to age, gender, income, education, health, and household composition are more likely to report negative experiences from heat.

Prior literature has considered how self-reported experiences with extreme events align with objective sources of data and has explored its connection to climate risk perceptions and policy preferences (e.g., Esplin et al., 2019; Howe et al., 2014; Howe and Leiserowitz, 2013; Zanocco et al., 2018). While studies have found evidence that subjective reported experiences with extreme weather can generally align with objective data, developing this correspondence can be difficult given the frequent mismatch in scale, resolution, temporal horizon, and data collection periods between survey and objective data. We propose that objectively measured high-temperature experience, which is similar to other extreme weather events with impacts that can be widely distributed across populations (Zanocco et al., 2022b), will form such a correspondence with subjective, self-reported negative experiences from recently occurring heat events. We therefore form the following hypothesis:

(H2) Those living in areas with more frequent high temperature experience are more likely to report negative experiences from heat.

A growing body of literature relates negative experiences with extreme weather events with support for climate-related policies (e.g., Broomell et al., 2015; Demski et al., 2017; Gärtner and Schoen, 2021; Howe, 2021; Zanocco et al., 2019). Conclusions from the literature are mixed, and the evidence is not conclusive. In terms of adaptation measures for mitigating heat impacts, a range of policies have been proposed (Adnan et al., 2022; Degirmenci et al., 2021). For reducing local outside air temperatures, some of these adaptation policies have included expanding urban greening programs (e.g., tree canopy cover) (Wong et al., 2021; Ziter et al., 2019) as well as use of heat absorbing materials on urban surfaces (e.g., reflective coatings) (Cheela et al., 2021; Wang et al., 2021). For reducing indoor air temperatures, building cooling-related policies have been proposed for increasing the deployment of active technologies (e.g., air conditioning) as well as passive techniques (e.g., building materials and design) (Bhamare et al., 2019; Gabbe et al., 2023; Khosla et al., 2021). We contend that due to the visceral and persistent nature of these 2022 extreme heat events, experience will be influential in shaping support for heat adaptation policies. Moreover, we posit that being located in an area with higher levels of heat exposure will also influence preferences toward heat adaptation policies. Given these proposed relationships between subjective and objective heat experience, and policy support, we form the hypothesis:

(H3) Those with higher levels of reported negative experiences with heat and more frequent high temperature experience are more likely to support heat-related adaptation policies.

To test these hypotheses, we collected data in Germany, a European country that was severely impacted by extreme heat during the summer of 2022. To do so, we deployed a post-event survey of the German public and asked respondents about their experiences with heat in the summer of 2022 as well as their support for heat adaptation policies. Our motivation for choosing Germany for this research inquiry is as follows: First, literature investigating extreme heat experiences and heat vulnerability in Germany is scarce compared to other areas of the world (Beckmann and Hiete, 2020; Laranjeira et al., 2021; Osberghaus and Abeling, 2022) and very little prior research has examined heat perceptions and objective heat exposure within this context. Second, even as Germany is experiencing increasingly warm summers, a national heat action plan has not yet been fully developed, with the handling of extreme temperatures largely falling to local authorities, with many to date lacking comprehensive strategies (Deutsche Welle, 2023; UNDRR, 2021). In this sense, understanding German public support for heat adaptation policies, especially among those with higher reported impacts from heat, can directly contribute to these policy discussions. Finally, at the time of conducting this survey, Germany had just experienced its hottest summer on record, and this research offers unique insight into German experiences with extreme heat. This provides a window into extreme heat experiences that may become even more commonplace under future warming.

2. Materials and methods

2.1. Data

We conducted an internet-based survey of German residents from November 29 – December 19, 2022. Recruitment and survey administration were managed by YouGov, an online-based research firm. To administer surveys, YouGov quota samples from an opt-in internet panel comprised of registered panelists. These panelists are recruited in a variety of ways, including online advertising, strategic partnerships, affiliate networks, and websites. Panelists are then invited to take part in surveys and are compensated for their

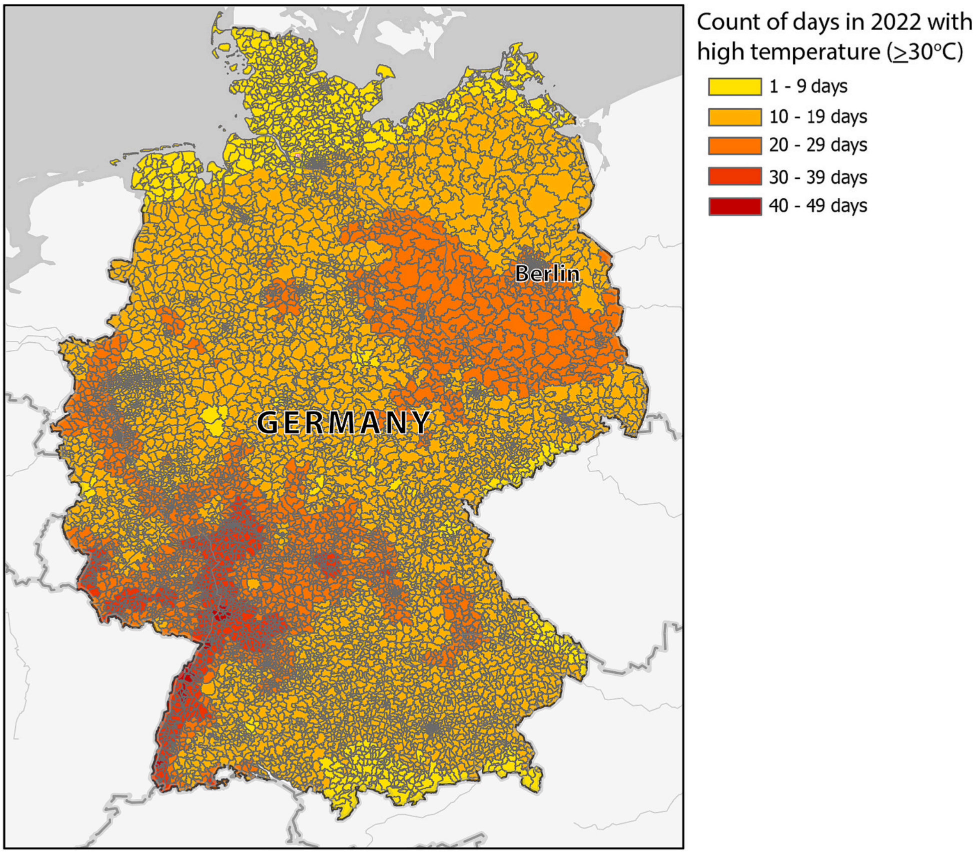

Fig. 1. Count of high temperature days defined as maximum air temperature greater or equal to 30 °C spatially averaged by German five-digit postal code areas. See DWD CDC (2022) for more information.

participation. See YouGov (2023) for more information about YouGov's survey methodology and Ansolabehere and Schaffner (2014) for a comparison of opt-in internet panels to probability-based sampling methods. In total, we surveyed 2356 participants who were 18 years of age or older and asked them about a range of topics, including perceptions of their surrounding environment, recent experiences with extreme weather events, and support for government policies. As part of this survey, respondents also provided information about their sociodemographic and household characteristics. In this study, we focused on responses to survey questions related to experiences with hot weather in the summer of 2022 as well as support for local governmental policies related to heat adaptation. The survey instrument was first written in English, then translated in German, and administered in German to survey participants. The text from survey questions reproduced in this article are from the English language instrument.

In addition to the responses from our survey, we also applied a national-level gridded air temperature dataset produced by Deutscher Wetterdienst (DWD), Germany's Climate Data Center (DWD CDC, 2022). This product is a dataset of annual counts of hot days, defined by DWD as a day where the maximum daily air temperature is greater than or equal to 30 °C, with estimates provided at a 1 km × 1 km grid resolution for 2022. We then spatially averaged the count of hot days grid cells across German five-digit postal code boundaries, producing an average count of hot days (hereby referred to as "high temperature days") per postal code in 2022, displayed in Fig. 1. As an additional measure, we used a similar approach to generate average yearly high temperature days per postal code from 1991 to 2020. This measure was applied in an alternative analysis that is presented in Appendix Tables A8 & A9.

2.2. Measures

Guided by previous literature about vulnerable populations (Beckmann and Hiete, 2020; Osberghaus and Abeling, 2022; Schoessow et al., 2022), we formed the following measures from our survey data which we then applied in our analysis. These measures included gender (male = 46.9%, female = 53.1%), age (65 or older = 21.8%), education level (university education = 34.0%), and finances, which we measured via respondents' difficulty in paying bills or meeting household expenses (very difficult to pay bills = 12.2%). We also considered household characteristics such as the total number of people in the household (mean = 2.3) and whether respondents lived in a household where at least one occupant (including the respondent) had a chronic medical condition such as heart or lung disease, asthma, or diabetes (occupant(s) with chronic medical condition = 27.6%).

Drawing on literature about impacts of heat on work performance, comfort, and health (Flouris et al., 2018; Nazarian and Lee, 2021; Obradovich et al., 2017; Szewczyk et al., 2021), we asked respondents about their experience with heat "During the past summer…" using four related questions with responses on a five-point scale from 1 = "Never" to 5 = "More than once a week". These included: "…how often have you experienced decreased productivity at work from heat?" (mean = 2.58); "…how often have you experienced difficulty falling asleep from heat?" (mean = 2.81); "…how often have you experienced personal discomfort from heat? (mean = 2.55); and "…how often have you experienced heat-related illness, such as heat exhaustion or heat stroke from heat" (mean = 1.59). Additionally, we combined these four heat experience impact measures by taking their mean and forming a composite measure of average negative heat experience (mean = 2.25) which had acceptable internal reliability (Cronbach alpha = 0.794) (Tavakol and Dennick, 2011).

Selecting from a range of heat adaptation-related local policies (Degirmenci et al., 2021), we asked respondents to provide their level of agreement ("Do you agree or disagree that your local government should…") with various heat-related policies situated on a four-point scale from 1 = "Strongly disagree" to 4 = "Strongly agree". These included: "…plant more trees along streets to address the impacts from very warm weather" (mean = 3.35); "…apply sun reflective coatings on pavement and rooftops to address the impacts from very warm weather" (mean = 2.89); and "…subsidize residential air conditioning to address the impacts from very warm weather" (mean = 2.59).

In addition to these self-reported measures derived from our survey (i.e., subjective data), we also applied a measure of cumulative high temperature days in 2022 derived from temperature observations (i.e., objective data). To do so, we joined the respondents' five-digit postal code to the count of the high temperature days spatially averaged across postal codes (Fig. 1) and obtained an estimate for the count of high temperature days experienced by our survey respondents in 2022 (mean = 18.86).

2.3. Analysis

We applied these measures within a two-stage analytical approach to test our proposed hypotheses. In the first stage of our analysis, we examined the relationship of individual and household characteristics and objective heat experience to reported negative experiences with heat during the summer of 2022. To do so, we used linear regression models to predict experience with heat, fitting models predicting each of the four negative heat impact experience measures as well as average negative heat experience. As covariates in these regression models, we included personal and household characteristics relevant to heat vulnerability, alongside our measure of objective heat experience. In the second stage of our analysis, we explored factors that shaped support for local heat adaptation-related policies. We pursued a similar analytical strategy by predicting each policy using linear regression and the same individual and household characteristics as covariates, while also including average negative heat experience. All model coefficients presented in the main text figures are standardized by two standard deviations (Gelman, 2008) and unstandardized coefficients are available in the Appendix (Tables A1 & A2).

To assess the robustness of our findings we conducted the following alternative modeling, presented in the Appendix. We first conducted ordinal logistic regression for models predicting negative heat experience (Appendix Table A3) and support for local heat adaptation-related policies (Appendix Table A4) and did not find any substantive differences compared to the results presented in the main text (Fig. 3 & Fig. 5). Next, we fit linear regression models predicting local heat adaptation-related policy support using each of the negative heat experience measures in separate models (Appendix Tables A5 – A7). Separate inclusion of the heat experience measures as covariates did not produce any notable differences in terms of directionality and magnitude of effects. Finally, we applied an alternative objective measure, average yearly high temperature days (1991–2020), in models predicting negative heat experience and heat adaption-related policy support (Appendix Tables A8 & A9). We found that this historical temperature measure operated similarly to our objective measure of high temperature days in 2022. To align with our survey respondents' self-reported negative heat experiences, we presented models with high temperature days derived from 2022 data in the main text of this article.

3. Results

3.1. Negative impacts from heat

Our survey respondents reported their experiences with heat during the summer of 2022 across four negative impact types: heat-related illness, difficulty falling asleep or staying asleep, personal discomfort, and decreased productivity (Fig. 2, a). Among our sample, the most frequently occurring negative impact was difficulty falling asleep or staying asleep (mean = 2.81), which occurred on average "every 2-4 weeks". The next most frequently occurring impacts were decreased productivity (mean = 2.58) and personal discomfort (mean = 2.55), with both measures occurring on average between "less than once a month" and "every 2–4 weeks". The least reported impact among our sample was illness from heat (mean = 1.59), which on average was reported as occurring between "never" and "less than once a month". Overall, 84.6% of respondents reported some level of negative experience with heat for at least one of the listed impact types.

We then further decomposed these reported negative experiences with heat across selected vulnerable groups (Fig. 2, b). Overall, there was a higher frequency of negative impacts from heat among women, those who had difficulty paying bills, and for households with occupants with chronic medical conditions. Levels of impacts from difficulty sleeping and discomfort from heat had consistent disparities among vulnerable groups who had difficulty paying bills or household occupants with chronic medical conditions. Women

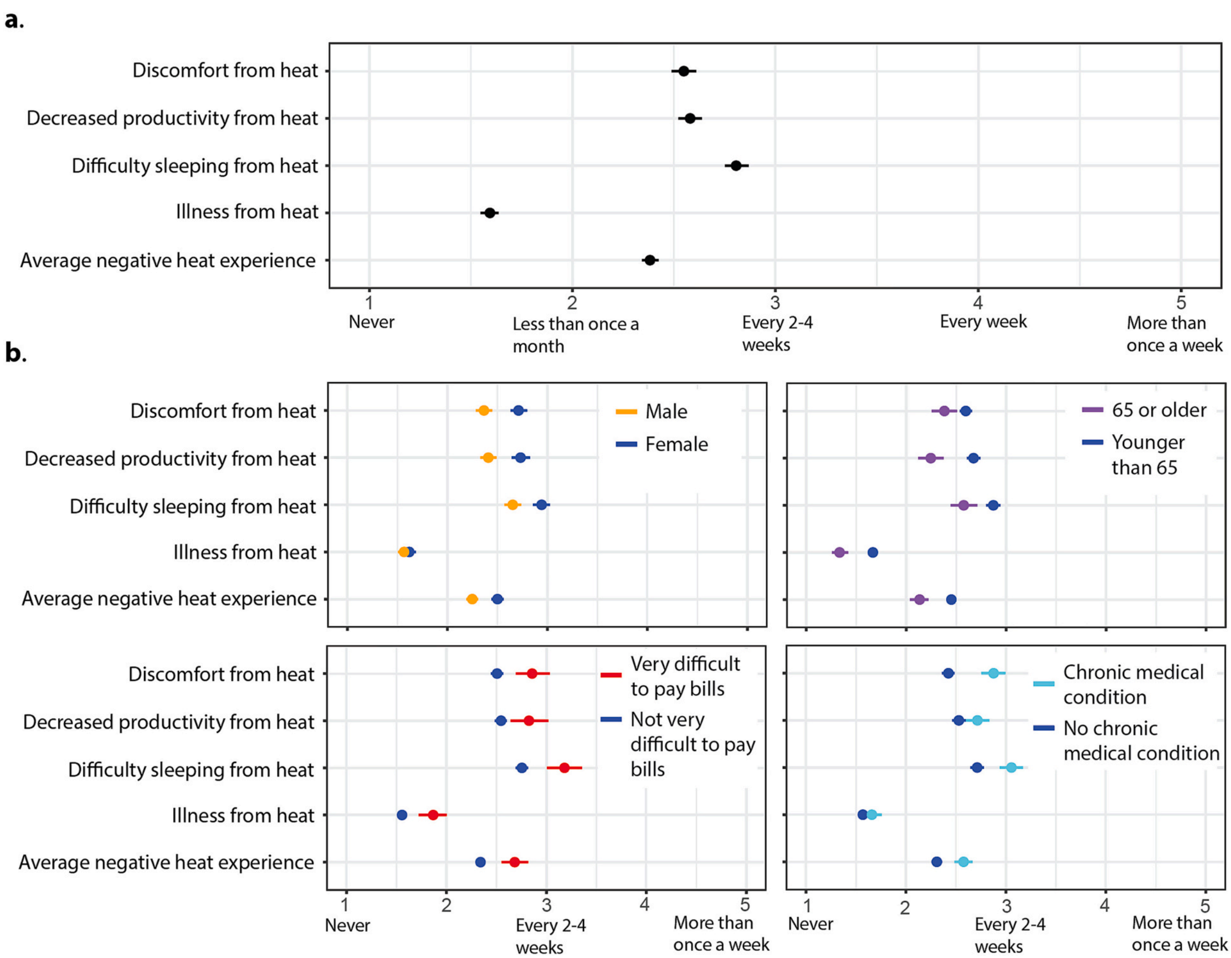

Fig. 2. a. Negative heat experiences across the entire sample of German residents for selected impact types. b. Negative heat experiences for selected vulnerable groups. Points represent means and lines 95% confidence intervals.

were also found to have higher impacts from heat compared to men across all measures except for illness from heat. However, we found that those who are elderly (65 or older) were less likely to report negative experiences from heat across all included impact types.

To further examine the factors related to heat experience, we modeled each negative heat experience impact measure using respondent characteristics and objective heat experience (Fig. 3). We found some of the same patterns previously identified in Fig. 2 with respect to vulnerable characteristics. Male respondents and those who are 65 years or older were associated with lower impacts from heat, while those with difficulty paying bills and those with household occupants with chronic medical conditions reported higher impacts from heat. Across the negative heat experience impact measures, there were inconsistent relationships for educational attainment and size of the household. Those with a university degree were less likely to report difficulty sleeping but not for other negative experiences with heat, while the number of household occupants was associated with higher levels of discomfort and illness from heat. Finally, our objective measure of heat experience, count of days greater or equal to 30 °C, was statistically significant in all models. The general patterns identified for these individual negative experiences from heat were also found when predicting average negative heat experience. This led us to partially accept our first hypothesis (H1) and fully accept our second hypothesis (H2). For H1, those with vulnerable characteristics were more likely to report negative experiences with extreme heat; however, this was not the case for all the vulnerable characteristics we considered, most notably so for older respondents (65 or older) who reported lower levels of negative experiences. For H2, there was a positive relationship between our objective and subjective measures of heat experience that was consistent for all models tested.

3.2. Drivers of support for local heat adaptation policies

We explored support for local government policies intended to mitigate the effects from heat for three proposed policies: planting more trees along streets, applying sun-reflective coatings on pavement and rooftops, and subsidizing residential air conditioning (Fig. 4). We found that planting more trees along streets had the highest levels of support, with over 80% of the sample either somewhat or strongly agreeing with this policy. While having less support than planting trees, two-thirds of the sample were supportive of applying reflective coatings on pavement and rooftops. Compared to these other policies, subsidizing residential air conditioning had the lowest level of support, with approximately half of the sample agreeing/disagreeing with this policy.

We next modeled the relationship between personal and household characteristics and reported average negative heat experience and objective heat experience in predicting support for local policies intended to mitigate the effects of heat (Fig. 5). For planting more trees along streets, the policy with the most support among our sample, average negative heat experience was associated with higher levels of support. For individual and household characteristics, those with chronic medical conditions were more likely to support planting more trees along streets, as well as women more than men. We did not, however, find evidence of a relationship between

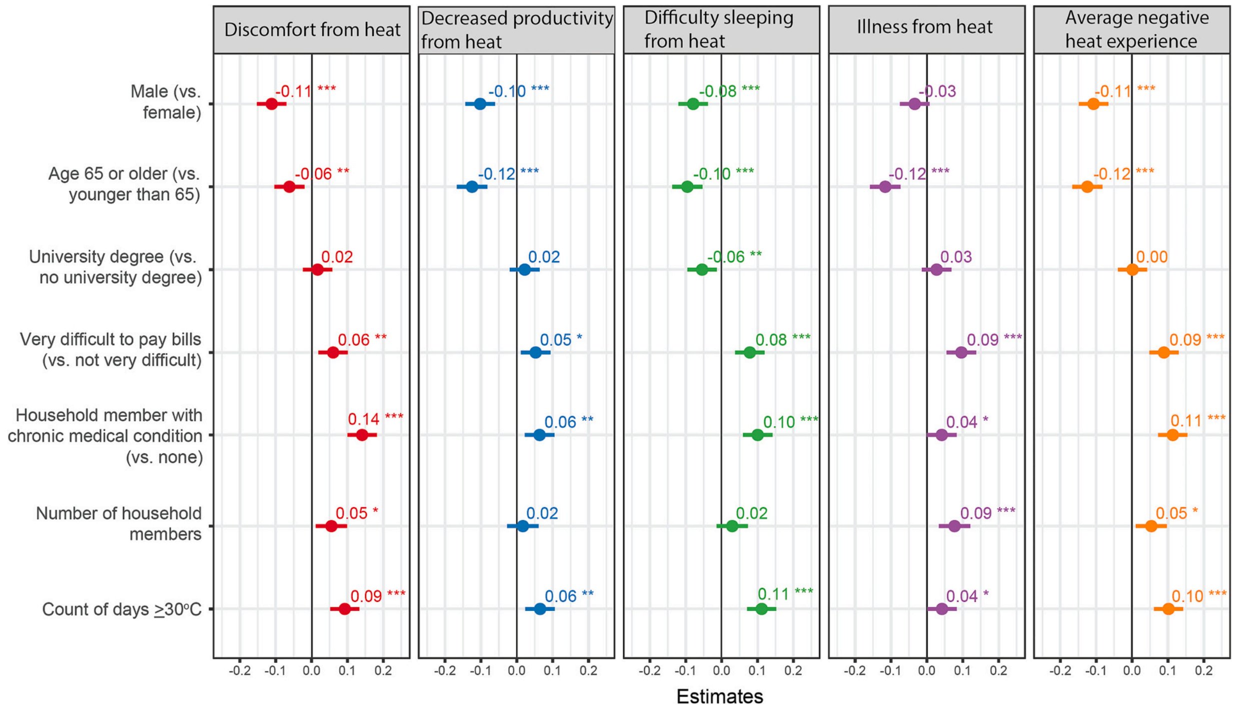

Fig. 3. Linear regression models predicting negative experiences from heat for each impact type and average negative heat experience for the sample of German residents. Points correspond to standardized coefficients and lines 95% confidence intervals. Statistical significance thresholds are denoted as * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. See Appendix Table A1 for regression outputs with unstandardized coefficients.

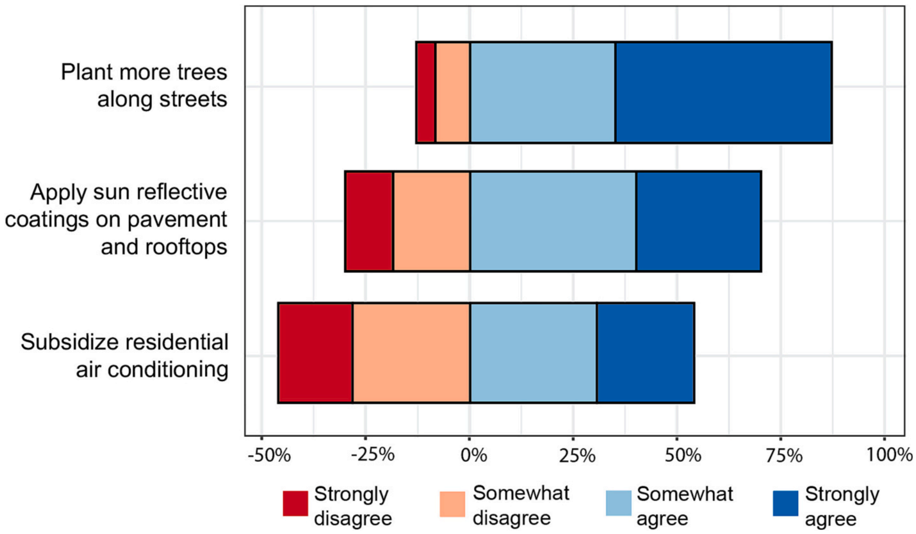

Fig. 4. Support for local heat adaptation policies among the sample of German residents.

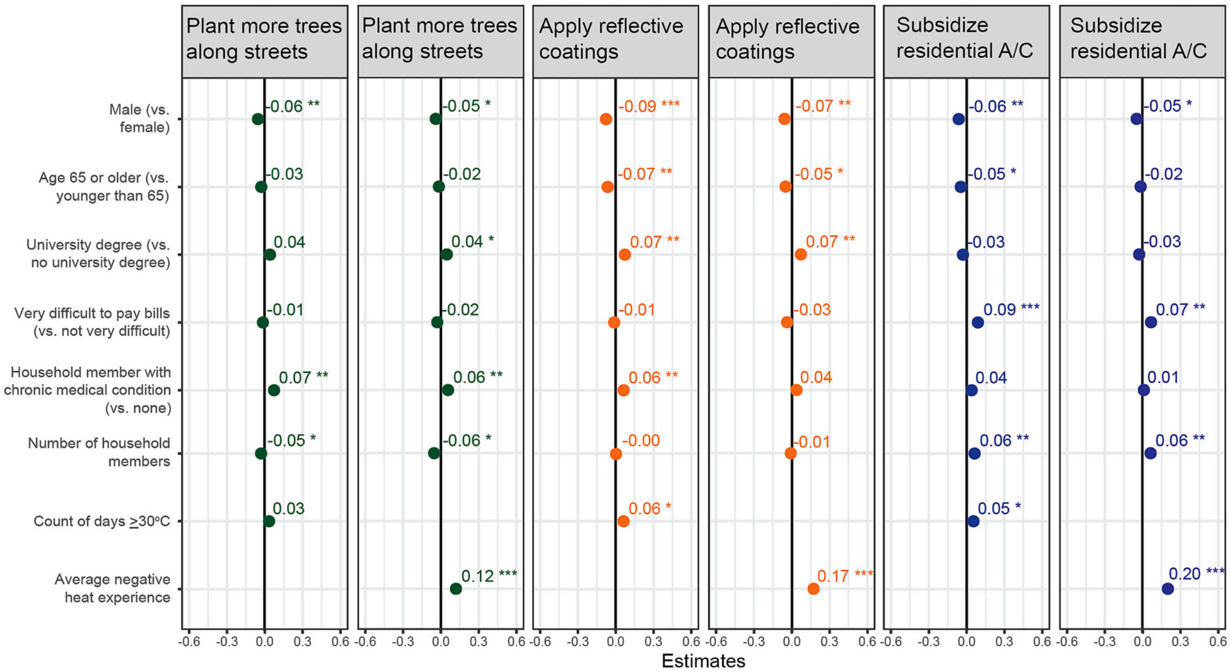

Fig. 5. Linear regression models predicting support for local heat adaptation policies for the sample of German residents. Points correspond to standardized coefficients and lines 95% confidence intervals. Statistical significance thresholds are denoted as * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. See Appendix Table A2 for regression outputs with unstandardized coefficients.

support for planting more trees and objective experience with heat (i.e., count of days greater or equal to 30 °C). With respect to the policy of applying sun-reflective coating on pavement and rooftops, we found a similar pattern with respect to individual and household characteristics; however, those with a university education were more supportive. We also found that self-reported average negative experience with heat was statistically significant and related to higher levels of support for applying reflective coatings. However, of note is that the count of days greater or equal to 30 °C was statistically significant and positive, which suggests that living in an area with more objective heat experience contributed to higher levels of support for applying reflective coatings.

Finally, we considered the most polarizing of the policies, subsidies for residential air conditioning to address the impacts from very warm weather. Here we found that those who reported difficulty paying bills and those who live in larger households were more supportive of subsidizing residential A/C, while those 65 years or older and male were less supportive. Similar to support for reflective coating on pavement and rooftops, we also found that self-reported average negative experiences with heat and objective experience with heat were related to higher levels of support for subsidizing residential air conditioning, leading us to partially accept our third hypothesis (H3). While our subjective measure of negative heat experience was strongly related to support for each of the proposed heat-adaptation policies, our objective measure (count of days greater or equal to 30 °C) was positively associated with policy support for two of the three listed policies.

4. Discussion

Our research revealed high levels of self-reported negative experiences with heat during the summer of 2022 among our sample of German residents. These experiences align with this summer being among the deadliest in Germany's history in terms of extreme weather, where over 8000 people were estimated to have died due to heat-related causes (Ballester et al., 2023). We also found that individuals with characteristics that make them more vulnerable to extreme heat events, such as having difficulty paying bills or living in households with occupants with chronic medical conditions, generally reported higher levels of negative impacts. Such differences in heat-related impacts suggest the burdens of hotter temperatures are not distributed equally among vulnerable groups in Germany and may worsen under climate change without comprehensive and inclusive policy actions.

Surprisingly, we found that elderly people (65 or older) were less likely to report negative experiences with heat, ultimately leading us to partially accept our first hypothesis (H1). It is well documented that during heat waves this age group is more likely to seek medical attention due to heat and are also more likely to die from heat-related causes (Gabriel and Endlicher, 2011; Kenney et al., 2014). At the same time, these results are in line with other recent studies from Germany that have provided a more nuanced picture of risk profiles, wherein young people experienced problems at higher rates than older people. For instance, in Augsburg, younger people were shown to have the highest heat risk perception of all age groups (Beckmann and Hiete, 2020), while in Bonn, young people reported impacts of heat stress at the highest rates (Sandholz et al., 2021).

Reasons for older populations to be less likely to report negative experiences with heat could also be related to socio-psychological factors (Abrahamson et al., 2009; Malmquist et al., 2022), such as different risk perceptions informed by their experiences with heat across their lifetimes but also because "implying they are unable to cope [with heat] may be offensive to those who value their autonomy" (Hansen et al., 2011, p. 4721). On the other hand, younger people may be more directly exposed to heat stress through their behavior, as they are more likely to have occupational and recreational activities that increase opportunities for exposure to heat (Sun et al., 2021), and a lack of coping capacity, as they are more likely to live in rented and comparatively poorly adapted apartments and with fewer green areas nearby (Sandholz et al., 2021). Furthermore, elderly individuals, especially those who are socially active and healthy, are often retired and thus no longer tied to rigid working schedules (Malmquist et al., 2022). This gives them greater flexibility to alter their daily routines as needed (Abrahamson et al., 2009). Regardless of the reason, that older populations were consistently less likely to report negative experiences with heat, when this population is known to be at higher risk of heat-related complications, is an area of research that merits further inquiry.

With respect to support for local government policies related to heat adaptation, we generally found strong support among German residents. The policy of planting more trees along roads enjoyed almost unanimous support, and even the least popular policy – subsidizing residential air conditioning – still had a narrow majority of support among our sample. In Germany, the prevalence of air conditioning is notably lower compared to countries like the United States (Davis et al., 2021). Despite increasingly warmer summers, many Germans are still resistant to the idea of air conditioning due to environmental concerns and the country's cultural emphasis on "airing", or *lüften* (which translates "to air out"). This attitude underscores the importance of context and cultural norms in shaping public policy preferences. However, it is important to note that while sociodemographic characteristics mattered for predicting policy support, self-reported negative experiences with heat were consistently among the most influential factors. In this sense, personal experience and perceptions are an important driver in forming preferences for heat-related public policies, which suggests that as these events become more frequent and severe, support for such policies may continue to grow.

In addition to important relationships with subjective, self-reported personal experience with heat, we found that experience measured objectively via daily maximum temperature also mattered. First, we found alignment between subjective and objective measures of heat experience, with those who reported higher levels of negative heat impacts also being strongly associated with living in areas that experienced higher counts of high-temperature days, which led us to accept our second hypothesis (H2). This correspondence between subjective and objective heat experience builds added layers of validity to our findings and study. Additionally, our research suggests that irrespective of self-reported experience, just being located in an area with more frequent higher temperature days was related to more support for two out of three policies intended to mitigate effects from heat, resulting in partial acceptance of our third hypothesis (H3). This is a compelling finding because it suggests that just being exposed to hot weather, without the additional step of relating this through personal experiences, may have an influence on policy support. This is consistent with literature that found similar effects for taking protective behaviors (Esplin et al., 2019) or being exposed to extreme weather hazards and increased support for adaptation-related policies (Zanocco et al., 2022b).

However, although we related recent objective experience with hot weather to our survey data, our research design does not allow for disentangling this relationship from broader patterns of temperature-related weather patterns experienced over longer time horizons. For example, in an alternative analysis, we found similar relationships in self-reported negative heat experience and support for heat adaptation policies using a longer-term measure (30 years) of average high heat daily exposure (see Appendix Tables A8 & A9). Longitudinal surveying, ideally of the same respondent across multiple years, could perhaps uncover some of these distinctions and help tease out whether these relationships are driven by heat exposure spanning multiple years, recent heat exposure, or a combination of both, or even other place-based or contextual characteristics. Additionally, future research could also consider how atypical a recent experience with hot weather is perceived compared to respondents' past experiences, and this could be further matched with objective temperature data to better understand how frequency, intensity, and abnormality of weather events may shape perceptions.

There are some important limitations to note for our study. The first is related to the survey – sampling was purposive and not probability-based (e.g., random sample of household addresses), so we are unable to claim representativeness for the population of Germany. This is a limitation of purposive sampling more generally, although the continual trend of declining responses rates for probability-based sampling presents its own set of challenges (Beullens et al., 2018; Stedman et al., 2019). Additionally, we surveyed Germans following what was, at the time, a record-breaking summer in terms of heat waves. If we had surveyed Germans during the heat waves, we might have received different responses, most likely greater in effect than what we reported here. We opted to survey later in the following season to avoid recency bias (Weber, 2010); however, as we asked about self-reported negative experiences, it is possible that some respondents were less accurate in recalling their experiences from the summer. Additionally, respondents could have also been influenced by warmer than average temperatures in the Autumn months prior to the survey administration period, with October 2022 being the second-warmest on record (Deutsche Welle, 2022). Another limitation to our research is related to how we collected information about vulnerable characteristics. For some vulnerable characteristics, such as chronic medical conditions, we chose to collect household data rather than personal information due to their more intrusive nature and to increase question response rates. However, this decision means we cannot directly link chronic medical conditions with personal experience, and the individual effects we observe may be different than what we have reported at the household level. With respect to our objective measure of heat experience, it is derived from outside air temperature and does not necessarily reflect actual respondent exposure throughout the day, such as air temperatures inside workplaces, households, etc. Our findings might therefore be different if we had access to such indoor objective heat exposure data.

5. Conclusion

We found evidence that a wide majority (85%) of Germans reported negative experiences from hot weather in 2022, and although these impacts may not always rise to the level of being medically significant, in aggregate suggest that heat had significant impacts on society. We found strong support for heat adaptation policies, especially among those who reported more negative experiences. While weaker in effect, being located in areas with higher objective heat exposure was also associated with more policy support. Currently, Germany, and the world, is in the midst of another record-breaking year in terms of high temperatures, with June 2023 breaking records as the hottest month in recorded history (Sanderson, 2023). Extrapolating our findings from this study suggests that Germans may also be significantly impacted by heat this year, and this experience could compound and result in even more support for heat adaptation policies. Indeed, the German government has started to draft plans around heat with proposals to help protect vulnerable populations during heat waves (Deutsche Welle, 2023). The rapid pace of climate change, however, demands immediate policy actions – some of which that could involve more effective communication on heat risk perception, particularly through targeted messaging for vulnerable populations like the chronically ill and elderly.

Our study also underscores the popularity of greening cities, an initiative that could be complemented by financial assistance for air conditioning or providing access to cooled, air-conditioned places during hot weather days. Traditionally, Germany's summers did not warrant the cost of installing and running air conditioning (Davis et al., 2021). Expanded air conditioning adoption in the future, whether incentivized through policy instruments or in response to thermal comfort needs, could place new strains on the German energy system and endanger its goal of being net zero by 2045 (Alkousaa et al., 2023; K. Hansen et al., 2019). For example, widescale utilization of energy-intensive cooling technologies can increase electricity demand during high temperature days to levels that may destabilize the grid and result in outages, as observed recently in the U.S. (Bergman et al., 2022; Sun et al., 2023). Moreover, increases in cooling-related electricity demand can also produce financial burdens for consumers and may mean that greenhouse gas emitting sources of generation are required to meet this increased demand (Davis and Gertler, 2015; Malik et al., 2022). This underscores the need for energy-efficient indoor cooling technologies, including passive cooling building designs (Bhamare et al., 2019; Yenneti et al., 2020) and convective cooling devices such as electric fans (Jay et al., 2019; Malik et al., 2022; Morris et al., 2021). Such technologies can potentially serve as more sustainable alternatives if made broadly accessible and affordable and may pose less challenges to decarbonizing the energy system while also helping to maintain human thermal comfort during hot weather.

As global temperatures continue to rise, Germany, and other areas of the world with less historical experience with heat waves (Ward et al., 2016), may need to continually assess and reassess approaches toward climate adaptation policies, especially with respect to actions that are sustainable and protect the most vulnerable. We urge the academic community, as well as emergency managers, city planners, and others engaged in the policy process to further develop methods for measuring heat impacts on populations – some of which we propose here via post-event surveying – and design long-term policy approaches that can mitigate future impacts from heat.

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CRediT authorship contribution statement

Chad Zanocco: Conceptualization, Methodology, Formal analysis, Data curation, Writing – original draft. **Rita Sousa-Silva:** Conceptualization, Methodology, Formal analysis, Data curation, Writing – original draft.

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

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.uclim.2023.101759.

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