Climate change experiences raise environmental concerns and promote green voting

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Climate change experiences raise environmental concerns and promote green voting

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Abstract: Public support is fundamental in scaling up actions to limit global warming. Here, we analyze the impact of exposure to climate extremes on environmental concern and Green voting for 29 and 24 European countries, respectively. Combining high-resolution climatological data with regionally aggregated and harmonized Eurobarometer surveys and European Parliamentary electoral data at the subnational level, we find a significant and sizeable effect of temperature anomalies, heat episodes and dry spells on environmental concern and voting. The effect sizes differ substantially and are most pronounced in regions with a cooler Continental or temperate Atlantic climate, and weaker in regions with a warmer Mediterranean climate. The relationships are moderated by regional GDP suggesting that climate change experiences increase public support for climate action but only under favorable economic conditions. The findings have important implications for the current efforts to promote climate protection in line with the Paris Agreement.

One-Sentence Summary: Exposure to climate extremes influences green concern and voting with regional variation across climatic and economic conditions.

Whilst about two decades ago, climate change and associated extreme climate events were psychologically distant for many Europeans, in the past years Europe has witnessed its warmest years on record resulting in climate-related disasters such as wildfires or droughts [1]. In fact, the series of heatwaves in Europe since 2015 has been the most extreme in the past 2,110 years [2], highlighting the urgent need for climate action.

While *individual* behavioral changes are an important element of mitigation action, decarbonization of the economy requires structural reforms that bring public and macroeconomic policies, such as taxes, subsidies, and government spending in line with the EU's ambition to move towards a climate-neutral economy. To fulfil its commitments under the Paris Agreement, the EU has pledged to cut at least 40% of its greenhouse gas emissions from 1990 levels while striving to achieve at least a 32% share for renewable energy by 2030 [3]. This requires radical transformations in production and consumption involving all sectors ranging from energy to land and agriculture, transport, buildings, industry and waste management. To achieve this transition, a broad support by the public is crucial.

In the past two decades, there has been a rise in awareness and concern for environmental issues across Europe, thanks partly to recent climate movements and media coverage [4]. Whereas in 2002, less than 5% of Europeans agreed that environmental issues should be a priority for their country, this proportion had more than tripled in 2019 (Fig. 1 a) with Nordic countries taking a leading role (Fig. 1 b). These changes can contribute to achieving the sustainability transformation by catalyzing public support for climate action and inducing policy change [5]. Indeed, a significant rise in the vote share of Green parties in the last European Parliamentary elections in 2019 reflects the increasing salience of the climate crisis and public concern about environmental and climate issues [6]. Between 2005 and 2019 the percentage of seats held by Green parties in the European Parliament increased by 105% from merely 5.7% to 11.7% (Fig. 1 c & d).

Understanding the drivers of changes in public concern and support for Green parties is important to identify the mechanisms underlying transformations towards a greener economy and more sustainable society. Here, we study the effect of increased experiences with climate extremes on environmental concern and analyze, for the first time, to what extent changes in concerns translate into actual political support for climate action in form of Green voting [7–10].We exploit time-series Eurobarometer data (42 survey waves, 2002-2019) and European Parliament election data (7 elections, 1990-2019) to analyze changes in concerns and voting at the subnational level across 29 and 24 European countries, respectively (Supplementary Tables S1 & S2). Our regional panel dataset allows us to causally test for the impacts of increased experiences of climate change while controlling for unobserved heterogeneity and time trends via the use of fixed effects.

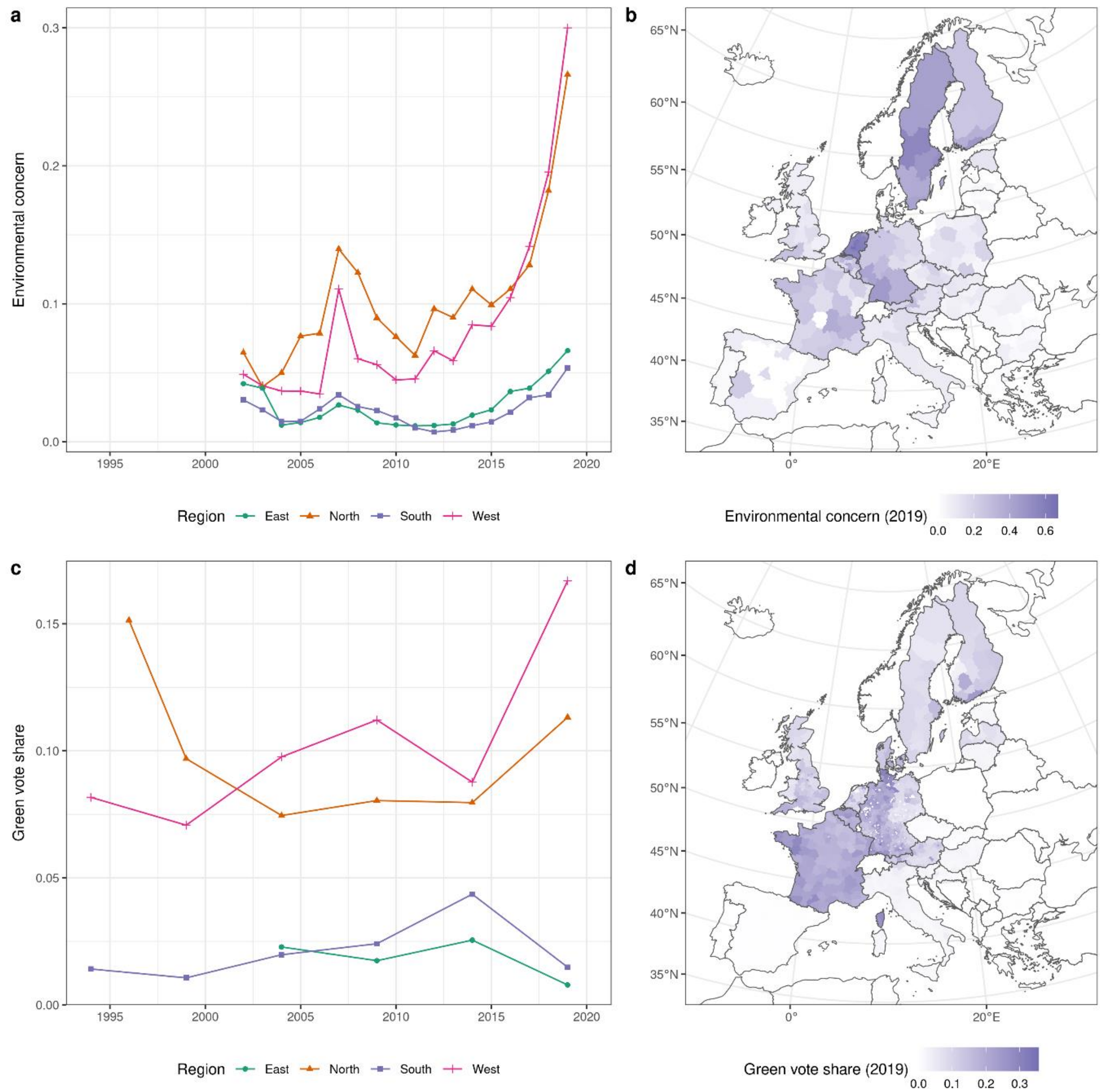

Figure 1 - Trends and patterns in environmental concerns and Green voting across Europe. a) Trends in environmental concerns from 2002 to 2019. The concern measure reflects the share of Eurobarometer respondents in a country who considered environmental issues to be important. b) Distribution of environmental concern by regions in Europe for the year 2019. c) Trends in Green voting in the European Parliamentary election from 1994 to 2019. Green voting reflects the share of voters in a NUTS region who voted for a Green party (see Methods for party classification). d) Distribution of Green vote shares by regions in Europe for the year 2019. Parties are classified as Green based on the party family variable in the Manifesto Project Dataset [11] and membership in the European Green Party.

Our study provides three key contributions to the understanding of the underlying factors driving public opinion on environmental issues and climate change. First, we overcome the common empirical difficulty of capturing how concerns are translated into action by directly investigating the linkages between environmental concerns and voting outcomes. Kachi et al. [9] argue that awareness of climate change alone does not necessarily translate into support for climate policy. However, very few existing studies have considered the link between direct exposure with extreme weather events or climate anomalies on political behavior [12,13]. Our empirical design allows us to causally test for the effects of experiencing climate change on Green voting. Second, exploiting European Parliament elections as well as the repeated cross-section of the Eurobarometer surveys, our study comprehensively provides insights for a broad number of countries and time periods. Third, we provide new empirical evidence on the relationship between economic conditions and public views on environmental issues, complementing previous findings in the empirical literature which are inconsistent [10,14].

Theoretical links between experiences, concerns and voting

An increasing number of studies have considered the role experiences with climate change play on the formation of attitudes and concerns about environmental and climate issues. Existing evidence shows that people who have experienced unusual weather and extreme weather events are more likely to believe in the existence of global warming and its anthropogenic causes [15,16], to express concern about climate change [17], to show willingness to engage in mitigation actions [18], and to be in favor of climate policies [19,20].

While the majority of studies show that experience matters, its relevance and the magnitude of the influence differ widely across the study contexts and types of experiences considered [8]. How and whether perceived changes become relevant is influenced by a range of individual characteristics and contextual factors (Fig 2). These include beliefs about local climate conditions and changes [10,13] and economic factors that may compete with environmental concerns. Especially during times of economic uncertainty, such as in the aftermath of financial crises, individuals may opt to prioritize economic and financial needs [21,22]. Other influential factors are related to individual ideological predispositions, political worldviews, and belief systems [10,13] as well as demographic factors including age, gender and education [23].

For a direct exposure, construal theory predicts increased levels of environmental concerns as the psychological distance between the individual and climate change impacts is reduced [24–26]. Experiences can reduce the psychological distance by making climate change and related hazards appear more certain (hypothetical distance) and temporally closer (temporal distance) as opposed to an abstract threat in a distant future. At the same time, experiences can make people understand that climate change affects them personally and their neighborhoods (spatial distance) and not a distant social group, who they have no relations to (social distance). Ample evidence from psychology and cognitive sciences confirms that risk perceptions, beliefs and concerns are particularly influenced by recent or common events such as wildfires, hurricanes and floods that are more cognitively ‘available’ (availability heuristics) [27–30].

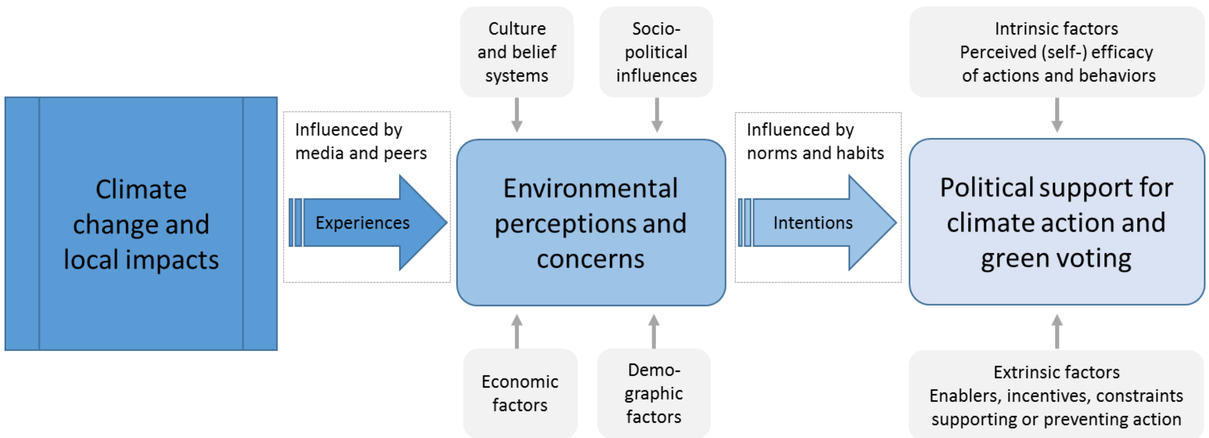

Figure 2 - Simplified conceptual model of the links between climate change experiences, environmental concerns and Green voting. Blue boxes and arrows highlight the causal pathways considered in our empirical analysis. Direct experiences with climate change and its local impacts influence environmental perceptions and concerns together with indirect experiences shared by the media and social networks. The relationship is moderated by contextual influences, such as culture and belief systems or economic factors, which determine to what extent experiences are translated into concerns. Concerns can result in behavioral intentions, with the choice of actions being influenced by norms and habits. If different intrinsic and extrinsic conditions are met, intentions can result in behavioral changes, such as increased political support and Green vote. Illustration is adapted from [31].

Whether concerns are translated into behavioral intentions and ultimately actions depend on intrinsic and extrinsic factors as well as habits and norms that shape behavioral responses to external stimuli [31]. While there is a broad literature connecting concerns, intentions and actions, only few studies have directly considered climate change impacts on voting and electoral outcomes. Existing studies show that climatic factors can indeed influence voting behavior such as voter turnout [32,33], votes for the incumbent party [33], or pro-environmental voting in climate-related ballots [12,13].

Results

Experiences influence both concerns and voting

Table 1 shows the results of fixed effects panel models, which regress the share of the environmentally concerned population in a region (columns 1–4) and the share of Green voters (columns 5–8) on climate variables which capture temperature anomalies and heat and drought episodes in the past 12 months prior to the concern measurement or election date. The estimates are standardized [34] and corrected for spatial and temporal autocorrelation [35] (see Supplementary Tables S3, S4 for autocorrelation tests, Tables S5, S6 and Figures S1-S4 for summary statistics).

They are robust to different sensitivity tests (Supplementary Tables S7-S13), including estimating dynamic models controlling for the lagged dependent variable (Supplementary Table S8), models with additional time-varying controls (Supplementary Table S11), and changing the climate variable measurement (Supplementary Tables S12 and S13).

Table 1 - Baseline effects of climate extremes on environmental concerns and Green voting

	Dependent variable:							
	Environmental concern				Green vote share			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Temperature anomaly	0.183***				0.115**			
	(0.024)				(0.055)			
Heat episode (temp.)		0.151***				0.183***		
		(0.026)				(0.055)		
Heat episode (UTCI)			0.120***				0.113**	
			(0.028)				(0.054)	
Dry spell				0.085**				0.234***
				(0.040)				(0.052)
Unit fixed effects	×	×	×	×	×	×	×	×
Period fixed effects	×	×	×	×	×	×	×	×
Season fixed effects	×	×	×	×				
Spatial cutoff (km)	500	500	500	500	500	500	500	500
Temporal cutoff (years)	1.5	1.5	1.5	1.5	5	5	5	5
Observations	10,263	10,263	10,263	10,263	5,682	5,682	5,682	5,682
R^2	0.478	0.473	0.468	0.464	0.768	0.772	0.768	0.777

Note: Standardized regression coefficients with standard errors in parentheses. Standard errors were corrected for cross-sectional and serial correlation up to the indicated spatial and temporal cutoffs. All models control for regional and temporal fixed effects to account for unobserved heterogeneity and common time trends. Period fixed effects refer to three-year periods in models 1–4 and election year fixed effects in models 5–8. Coefficients are standardized using the residual variance after applying the fixed effects. Accordingly, the coefficients refer to a marginal effect of a one standard deviation change of the covariates on the outcome within regions and periods. Temperature anomaly is defined as standardized deviation from the long-run monthly temperature mean; heat episode (temp.) is defined as at least three consecutive days with a mean temperature above the local monthly 95 percentile; heat episode (UTCI) is defined as at least three consecutive days with a mean UTCI above the local monthly 95 percentile; dry spells are defined as mean of SPEI below –0.5. All measures are calculated using 1971–2000 as reference period. P-values: * < 0.1, ** < 0.05, *** <0.01.

Experiences with temperature anomalies, heat episodes and drought events are found to significantly increase environmental concerns and the tendency to vote for Green parties. While there are some differences across models, with temperature anomalies and heat waves exerting the strongest effects on concerns and dry spells on voting for Green parties, all climate measures consistently have a positive relationship with the two outcomes. The magnitude of the estimated effects is sizeable. For example, a temperature anomaly of one standard deviation in the past 12 months is estimated to increase environmental concerns on average by 0.183 (SE 0.024) and Green voting by 0.115 standard deviations (SE 0.055) within regions, or by 0.9% and 0.3% in absolute terms (Supplementary Table S14). Likewise, an additional heat day per month is estimated to raise green concerns and voting by 0.8% and 0.7% respectively (Supplementary Table S15).

Positive temperature anomalies have a stronger influence than negative ones

Not only does climate change lead to higher temperatures and more extensive heat and drought episodes, it can also cause more extreme cold weather and temperature fluctuations, including cold snaps. Negative temperature anomalies and periods of extreme cold have commonly been used by climate sceptics to spread misinformation about global warming [36]. In additional models (Supplementary Table S17), we test for the impact of negative temperature anomalies, cold spells and wet episodes on concerns and voting and analyze how their influence differs from the influence of positive temperature anomalies, heat episodes and dry spells, for which we observe a similar effect as in the baseline models. For negative temperature anomalies, cold episodes and wet spells, on the other hand, no consistent influence is found. Overall, the results suggest a stronger relevance of positive temperature extremes and heat-related events for environmental concerns and Green voting (Supplementary Figure S5).

More recent events are more influential

In additional models, we tested for the role of time in shaping the influence of climate extremes on concerns and voting outcomes (Supplementary Table S18 – S21). While extremes are still found to have an influence even over greater time horizons, a recency effect is evident. More recent climate events tend to influence concerns and voting more strongly possibly due to a greater salience of the experiences. For example, heat episodes that occurred in the past 12 months (Supplementary Table S19) increase concerns and voting by 0.151 (SE 0.026) and 0.183 (SE 0.055) standard deviations, respectively. For a lag of 24 months, these effects diminish to 0.110 (SE 0.019) and 0.150 (SE 0.050), and for 48 months to 0.070 (SE 0.019) and 0.087 (SE 0.047), respectively.

Impacts of extremes differ across Europe

Regions across Europe are characterized by different climatic conditions and are differentially affected by climate change [37]. In additional interaction models (Figure 4), we test for the differential impact of climate extremes on concerns and voting across the main climate zones of Europe (Supplementary Table S22). Based on the Köppen-Geiger typology (Supplementary Figure S6), we distinguish between: (1) a hot, arid climate in the Mediterranean, Southern

European regions; (2) a temperate climate mainly in Western Europe; and (3) a colder climate, mainly in Northern and Central Europe.

We find that the impacts of climate extremes are not uniform, but differ from region to region (Figure 3). Temperature anomalies, heat episodes and droughts have a consistently stronger effect on concerns and voting in regions with a temperate and colder climate compared to regions with a warm, arid climate in the Mediterranean regions, for which we find no significant effects. In the temperate and cold climate zones, an increase in heat episodes (temp.) by one standard deviation is estimated to increase concerns by 0.205 (SE 0.027) and 0.185 (SE 0.033) standard deviations, and voting by 0.232 (SE 0.040) and 0.174 (SE 0.047) standard deviations, respectively.

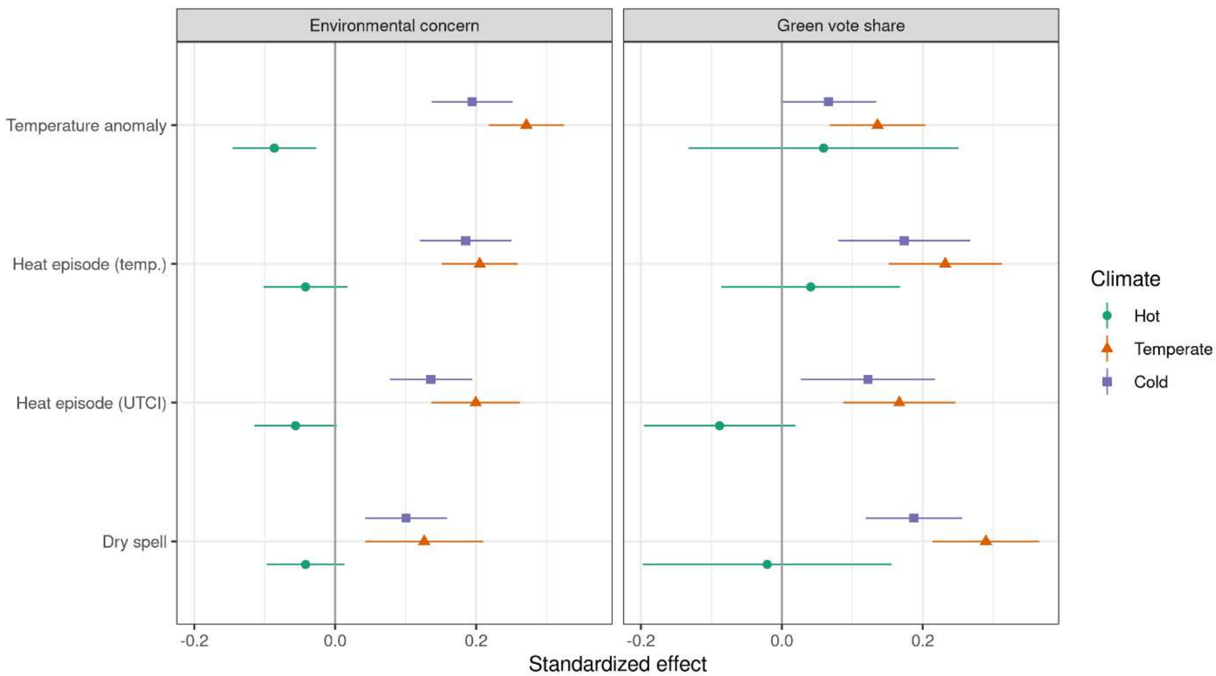

Figure 3 - Effects of climate extremes on environmental concern and Green voting by region. Coefficients are standardized using the observed variance of the variables in the given region after applying the fixed effects (see supplementary Table S22 for the full models). Models include period-region effects to account for region-specific time trends. Lines around the point estimates show the 95% confidence intervals. Regions are classified as “hot”, “temperate”, and “cold” based on the Köppen-Geiger typology (Supplementary Figure S6)

As the Mediterranean climate is already hot and dry in absolute terms, a marginal increase or deviation may have little to no effect on environmental concern and voting. Populations in these regions may have already adapted to the hotter baseline conditions, for instance through air conditioning and well-insulated housing. These findings highlight important differences across Europe in the way how the public responds to extreme climatic conditions and impacts showing the importance of understanding the spatial dimension of environmental concerns and public support for climate actions. The patterns are less clear for cold-related events and wet-spells, suggesting that changes in concerns and voting are mainly driven by experiences of extreme heat and dry spells, particularly in regions with cooler or more temperate climatic conditions (Supplementary Figure S7).

Economic conditions moderate climate impacts

To explore the underlying regional heterogeneity further, we estimate additional interaction models to test for the influence of economic factors in moderating the relationship between climate change experiences, concerns, and voting. Previous research has suggested that people's economic interests can lead to a crowding out of concerns for the environment, if there is a perceived trade-off between the two issues [22,38]. In the aftermath of the global financial crisis of 2007, for example, a substantial reduction in environmental concerns was observable across all European regions (Fig. 1A). Hence, in times of economic difficulty, the impact of exposure to climatic extremes on public support for climate action may be reduced. Here, we analyze whether climate impacts on concerns and voting depend on (1) the relatively stable, general economic condition in a region, measured in form of the mean GDP per capita in the period from 1995 to 2019, and (2) variable changes in the GDP that co-occurred with exposure to climate extremes.

We find consistent evidence that the effects of experiencing climate extremes on environmental concerns and voting are lower in regions with overall worse economic conditions (Figure 4). These effects also remain robust once other regional characteristics, such as the level of urbanization and education, as well as the regional climate zones are controlled for (Supplementary Table S23). Considering differences in mean GDP levels across regions, we find that the impact of temperature anomalies on environmental concerns is significantly reduced by 0.156 (SE 0.023) and on voting by 0.85 (SE 0.029) standard deviations for each one standard deviation decline in mean GDP (Table S23, Models 1 & 4). While we find consistent evidence for the importance of average differences in income between regions, changes in GDP over time are not found to moderate the climate effects.

As illustrated in Figure 4 (panels a and b), the impact of temperature anomalies on concerns and voting is much steeper in richer regions (GDP per capita above 75th percentile of income level) as compared to poorer regions (GDP per capita below 25th percentile of income level). The maps (panels c and d) highlight that differences exist not only between countries, but also within countries with wealthier regions responding more strongly to the exposure to climate extremes. Across Europe, the effects of experiences on concerns and voting outcomes appear to be particularly pronounced in urban centers with their relatively wealthier populations.

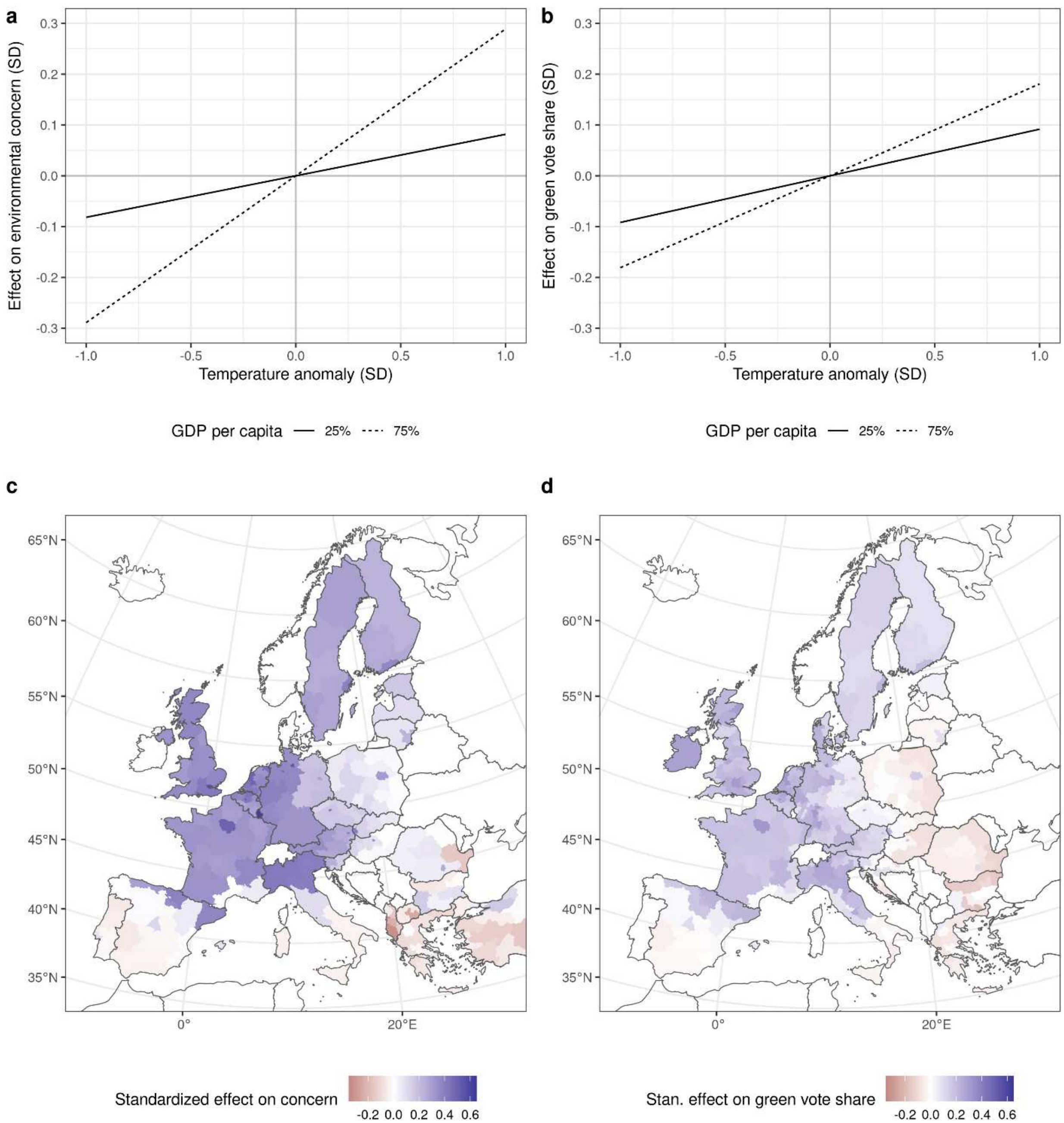

Figure 4 – Estimated marginal effects of temperature anomalies conditional on regional economic conditions. a/b) Marginal effects of temperature anomaly on environmental concerns / Green vote share at the 25th and 75th percentile of income level in terms of log real GDP per capita at purchasing power parity. Estimates are based on interaction models displayed in Supplementary Table S23, model 1 & model 4. c/d) Marginal effects of a one standard deviation temperature anomaly on environmental concern / Green vote share, given regions' GDP level and climate zone. Estimates are based on interaction models displayed in Supplementary Table S23, model 3 & model 6.

Changes in concerns explain climate impacts on voting

The conceptual model in Figure 2 assumes that experiences of climate extremes activate environmental concerns, which in turn influence Green voting. In this section, we extend our models to investigate to what extent climate-induced changes in concerns predict voting outcomes (Supplementary S24). In a first step, we regress the Green vote share in a region on the level of environmental concerns in that region one year and two years prior to the election (lag). As a falsification test, we also regress the Green vote share on the level of environmental concerns one year and two years after the election (lead), which should not have an effect. If environmental concerns in a region influence voting outcomes, we expect to see a positive effect in the first two, and no effect in the latter two models.

The results suggest a sizeable influence of changes in environmental concerns on voting outcomes. A standard deviation change in average concerns one year prior to an election is estimated to lead to a 0.253 (SE 0.071) standard deviation increase in Green votes and the average two years prior to an election still to a 0.195 (SE 0.071) increase. In line with our expectation, the lead values of concerns are not found to exert any significant influence on voting outcomes, suggesting that voting is influenced by concerns and not just the realization of an unobserved underlying process.

In subsequent models (models 5 to 8), we use a two-stage instrumental variable approach to estimate the causal impact of changes in concerns on voting. Here the estimation focusses on the variation in concerns that is driven by changes in climatic conditions as an exogenous and relevant instrumental variable. This reflects the full causal chain depicted in Figure 2 from the experience of climate extremes which induces concerns about the environment to the change in voting behavior. Also this estimation suggests a positive impact of concerns on voting of similar size as estimated in the previous models.

Conclusion

With the global temperature projected to rise to 1.5 °C above pre-industrial levels between the 2030s and 2050s if the warming trend continues [39], delayed climate actions will lead to many irreversible consequences. Accordingly, how to best increase citizens' environmental concerns and support for climate action is of great relevance. Using a novel cross-country regional dataset for Europe, we show that exposure to climate extremes, in particular related to heat and dry spells, activates environmental concerns and promote Green voting

With the issue of climate change becoming more concrete and salient, this has activated people's willingness to engage in and support climate action [24], including on the political level in form of voting for pro-environmental parties. The estimated effects of climate experiences on voting behavior are causal and run through increased level of concern about the environment. These changes can contribute to shifts in the political landscape at a larger scale, given the increased share of Green voters across countries in Europe in recent years. Our findings are in line with existing case studies on the role of climate experiences for voting behavior providing comparative evidence on the phenomenon and highlighting its broader implications [12,13].

Obviously, exposure to climate change is not the ideal way to promote public concern and action. Climate communication and education can help filling the experience gap. Studies have shown that carefully designed messages in climate communications can reduce the psychological distance and promote mitigation behaviors [26,40]. Our findings further highlight the importance of increasing the salience of climate impacts in an inclusive way, particularly for the populations not directly affected by climate impacts. In this regard, it is important to communicate the implications of a future warmer climate in a clear and accessible manner.

There is also a need to address the substantial geographic differences in concerns and political support for climate action across regions in Europe, in particular with respect to differences by income levels. As suggested by Ronald Inglehart's post-materialist theory, residents of wealthier nations whose basic needs for physical and economic security have been met can afford to pursue other needs which are relevant for improving quality of life such as environmental quality [41]. This theory also hints that in difficult times such as economic recessions, value orientations towards post-materialist preferences can be given lower priority due to "a renewed prioritization" of material needs [42].

The differential effects of different climate measures on concern and voting seem to depend also on climatic zones in Europe. Temperature anomalies and extremes increase green concern and voting only in temperate regions, mostly located in Western Europe, and colder regions, mostly located in Northern and Eastern Europe. In contrast, in regions that are characterized by an arid, warm Mediterranean climate, the exposure to relatively higher temperatures does not affect concerns and voting systematically. These heterogeneous effects may reflect differences in exiting infrastructures and adaptation measures, for instance air-conditioning, which are influenced by the baseline climatic conditions.

Our findings are of high relevance for the current debates on how to best promote and effectively implement further climate change mitigation measures in line with the Paris Agreement. The EU aims at taking a leading position in the fight against global warming. At the same time, economic challenges, social and political disruptions, and the switching balance of geopolitical and economic power, might hamper the Union's ability to fulfill its role of a policy innovator, pioneering solutions that tackle the pressing challenge of the climate emergency in a sustainable fashion. There is a need for an inclusive and equitable approach to climate protection that comprehensively highlights the potential threats of climate change while taking into account the needs and fears of local populations [43,44].

Methods

We make use of a range of georeferenced data sources to measure the central outcomes of interest. Our analyses are carried out at the subnational regional level, where we connect information on changes in climatic conditions to environmental concerns and voting outcomes over time. The resulting panel dataset allows us to test for climatic impacts while controlling for unobserved heterogeneity and time trends via the use of fixed effect.

Environmental concern data

Environmental concerns are measured using 42 waves of the Eurobarometer survey, which provides harmonized data for all EU member and EU candidate countries. The Eurobarometer is a repeated cross-sectional series of public opinion surveys based on a random, multistage sampling procedure. The surveys are carried out in regular intervals on behalf of the European Commission and other EU Institutions and cover various topics of thematic relevance for the EU [45]. Here, we use information gathered in the standard Eurobarometer trend questions series about issues perceived as important problems in the respondents' own countries.

By assigning Nomenclature of Territorial Units for Statistics (NUTS) codes to the region of residence of each respondent, we construct a unique regional time series containing data for 29 countries and 277 subnational regions spanning across 18 years (2002–2019). The standard trend questions are typically collected in the Eurobarometer surveys three times a year during different seasons, allowing us to derive a nuanced picture of trends in environmental concerns throughout the year. All our models control for seasonal effects in form of season dummies.

As an indicator for environmental concerns, we use the share of respondents in each region who consider environmental issues to be among the two most important issues facing their country at the time of the survey. The answer categories to this question changed slightly over time. While until 2006 the questionnaires only listed an environment-related answer category i.e. "protecting the environment", the list was extended by adding another answer category: "energy related issues" afterwards. From 2011 onwards, the two separate answer categories were merged into a new category called "the environment, climate and energy issues". As our goal was to create a harmonized time-series for environmental concerns in Europe, we counted any responses referring to the environment as relevant irrespective of differences in the set of answer categories provided.

To account for potential difference in response behaviors by answer category types, we further tested whether any discontinuities in response behaviors were visible immediately before and after the changes in answer category types (Supplementary Table S25). Our results indicate no substantial changes in response behavior, suggesting that our estimation results are valid. We also reran our main models, restricting the data to different periods based on the answer categories available (2007–2019 and 2011–2019) in order to test whether the changes in answer sets affect our estimates of environmental concern (Supplementary Tables S9 and S10). All our results remain fully robust to these sampling changes providing further support to our findings on the impacts of climate change experiences on concerns over time.

Voting outcome data

To measure voting outcomes, we collected original data on electoral returns for European Parliament (EP) elections at the NUTS-3 level from national sources. The data covers 24 countries and contains information for six EP election rounds spanning 25 years from 1994 to 2019. A few European countries (Portugal, Cyprus, Malta, and Luxembourg) and the British region of Northern Ireland are not included in the data due to data availability issues. If major changes in regional boundaries occurred in a country, the election data were aggregated to the NUTS-2 level.

In a first step, we collected the vote shares for all parties participating in the election across sub-national regions. From this extensive list of parties, we classified parties as Green based on their party family classification in the Manifesto Project electoral program database [46], and their membership in the European Green Party, a federation of political parties across Europe supporting green politics, that forms the G-EFA parliamentary group in the European Parliament. Based on this information, we calculated the Green vote share as the fraction of valid votes for Green parties in each NUTS-3 region per election round. Each observation, then, is listed as a region-year election return.

Climatological data

The explanatory variables are constructed from gridded datasets of temperature, precipitation, and evapotranspiration. Temperature data comes from the ERA5 reanalysis product that uses a global climate model to interpolate the observed weather station data to an even 0.1° raster [47]. The raster is aggregated temporally to the daily means of the hourly mean temperature and then spatially to the daily regional means. In the calculation of the regional means the grid cells are weighted with the fraction which is covered by the respective region.

Based on region-day observations, we first calculate temperature anomalies as standardized deviations of monthly temperatures from the long-run monthly mean using 1971–2000 as a reference period. In the calculation of the positive (negative) anomaly the values below 0.5 (above -0.5) are set to zero before averaging.

As a second group of relative temperature measures, we define a heat episode as a period of at least three consecutive days with a mean temperature above the 95th percentile of the monthly long-run distribution, and a cold episode as a period of at least three consecutive days with a mean temperature below the 5th percentile. For each region-month the number of days classified as heat and cold episode are counted and rolling averages are computed, similar to the temperature anomalies.

As a third group of measures, we use the Universal Thermal Climate Index (UTCI) instead of the temperature to calculate heat and cold episodes, again using the 95th and 5th percentile as thresholds to define extremes (see Supplementary Table S13 for alternative threshold specifications). The UTCI represents a thermal comfort indicator accounting for the human physiological response to temperature, humidity, wind, and solar radiation [48].

Finally, dry and wet spells are measured using the Standardized Precipitation-Evapotranspiration Index (SPEI) based on the gridded climate data (TS4.05) from the Climate Research Unit (CRU) at the University of East Anglia [49]. The SPEI is the standardized water balance, defined as the difference between precipitation and potential evapotranspiration. Evapotranspiration captures the combined water loss of evaporation and transpiration by vegetation. Accordingly, positive SPEI values indicate a larger than usual water balance (wet spell) and negative values a smaller than usual water balance (dry spell). The water balance is accumulated over a rolling period of three months (SPEI3). The standardization is done using a log-logistic distribution based on 1971–2000 as a reference period.

Estimation methods

For our analysis, we combined the georeferenced concern and voting data at the NUTS level with the gridded climatological data to study the impact of variations in climatic conditions in a region. We test whether climate extremes affect environmental concerns and Green voting with a fixed effects panel model of the following form:

$$y_{it} = \beta C_{it} + \alpha_i + \delta_t + \theta_S + \varepsilon_{it} \quad (1)$$

Where y_{it} captures the share of the environmentally concerned population or Green voters in a region i at time t. Here, t refers to the month, when the Eurobarometer respondents were interviewed or when the elections were held. C_{it} is a set of climatic indicators capturing climate extremes that occurred prior to the concern and voting measurement. In our baseline, we consider the effects of extremes in the period 12 months prior, which allows us to broadly capture changes in the climatic conditions across all seasons. In additional sensitivity tests, the climate impact interval was broadened, showing slightly decreasing climatic impacts on concerns and voting with broader time intervals (Supplementary Tables S18-S21).

We include a region-specific intercept α_i in order to control for time-invariant factors (unobserved heterogeneity) that may confound the estimation, such as the general political orientation in a region, structural economic factors, and the degree of urbanization. In addition, we include time period fixed effects δ_t (three-year periods for the concern data, elections for the voting data) and season fixed effects θ_S (only for concern data) to control for time trends and seasonal changes that are common across all regions. As the occurrence of extremes within a region over time is plausibly exogenous conditional on geographic location and time trends, our model allows us to test for the causal impacts of climate extremes on concerns and voting.

All coefficient estimates are standardized making comparisons across models with different dependent and independent variables possible. We use the standard deviation of the fixed effects residuals for the standardization and thus consider only the locally relevant variance that is observed within regions over time. This way the coefficients can be interpreted as changes in concern and voting with a one standard deviation change in the respective climatic factor relative to its regional historical distribution [34]. Models using alternative standardization approaches are presented in Supplementary Tables S14-S16).

In additional models, we further extend the baseline model by including interaction terms to capture differences in climatic impacts by climate zones and economic conditions. Here, we rely on additional data provided by Beck et al [50] for the construction of the climate zones as well as data from the Annual Regional Database of the European Commission [51] for the measurement of regional incomes. Furthermore, we test for the impact of changes in concerns on voting by (i) regressing the voting outcome in year t on changes in environmental concerns in the past 1 and 2 years, and (ii) by using a two-stage instrumental variable approach, where in the first stage climate variables are used as instruments to predict changes in concerns, and in the second stage the Green vote share is regressed on concern predicted in the first stage.

Limitations

Our analysis comes with certain limitations, which are important for the interpretation of our results. The main purpose of our study is the estimation of impacts of climate extremes on concerns and Green voting across subnational regions in Europe over time. While the level of aggregation allows us to study the relationships for a broad sample of regions and time periods and to compare the role of local conditions in moderating the effects, individual drivers of environmental concerns and voting such as values and attitudes are not captured. Further work, especially at more disaggregated or individual levels is therefore needed to fully grasp the underlying drivers and mechanisms beyond what we can examine in this study.

Second, we rely on Eurobarometer and European Parliamentary election data to construct our main concern and voting outcomes. While these sources provide comparative longitudinal data for Europe over time, they may not capture all relevant aspects and facets of environmental concerns and Green voting decisions. Our concern measure was constructed based on a priority assessment of Eurobarometer respondents. Hence, it does not fully reflect the multi-dimensional nature of the concept of environmental concern, unlike more comprehensive indices, such as the New Ecological Paradigm (NEP) scale by [52] or the environmental concern scale by [53]. However, these measures are typically collected in case studies and are not available for comparative longitudinal analyses [54].

As for the concern outcome, the regional share of Green voters reflects political support for climate action in a simplified way. In addition, like the results of any election, the outcomes of the European Parliamentary elections can be influenced by voter turnout and selection effects, which were partially accounted for by considering within-regional changes and by controlling for common underlying time trends. Moreover, we are not able to capture all aspects of the supply side and political dynamics of the party system. Some countries might have more credible environmentalist parties; while in other settings longer-term party attachments might prevent environmental concern from turning into Green voting. Again, these influences are captured by the regional fixed effects in our empirical design, and hence are not expected to bias the estimation of climate impacts on voting.

Despite these limitations, this study adds important insights to the scientific literature on the experience, concern and behavior nexus. The use of the harmonized Eurobarometer data on environmental concern and Europe-wide election measures enables us to achieve comparability across regions and to construct the unique cross-regional trend dataset required for our analysis. Our findings do not only show the role climate extremes play in influencing concerns and voting, but also highlight the importance of regional factors, such as climatic and economic conditions. They can thus help to gain a comprehensive understanding of the underlying drivers of observed changes in concerns and voting patterns across Europe.

Data Availability

The regional data generated and analyzed during the current study will be made available in the Harvard Dataverse repository upon acceptance of the article, https://dataverse.harvard.edu

Code Availability

The data analysis was carried out in R. The complete codes used to generate and visualize the results reported in this study will be made available in the Harvard Dataverse repository upon acceptance of the article, https://dataverse.harvard.edu. All used packages will be acknowledged and cited in the source code file.

Conflicts of Interest

The authors declare no conflict of interest.

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