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Abstract

Political conflicts about energy and climate change policies often have local implications, yet little is known about local public opinion towards these policies. Here, we estimate support towards 26 climate change mitigation policies for 402 German counties and for up to four points of time using multilevel regression and poststratification. We find that local support for climate policies varies by up to 60 percentage points across German counties with large disparities between the rural and urban population. While support for the expansion of wind power plants and solar power plants have converged over the last years, attitudes on the phase-out of coal power have polarized across regions. Using a spatial panel analysis, we find that support for the expansion of wind and solar plants correlate with the actual development of solar and wind capacities in these regions. Moreover, the spread of climate policy opinion is strongly determined by spatial diffusion as change in one region positively influences the trajectory of policy opinion among its neighbors.

1. Introduction

Public acceptance of climate change policy is crucial for policy adoption [1]. Yet little is known about climate policy support at the local level and its temporal evolution despite the importance of understanding local variation in climate policy opinion. Local opinion patterns matter for three reasons: (i) the effectiveness of climate change messages depends on location [2], (ii) local conditions such as extreme weather events or infrastructure availability shape acceptance of climate policy [3], and (iii) spatial variation reveals local polarization of opinion across jurisdictions. Analyzing differences in climate change opinion at the local level can thus help to predict and understand local contestation of clean energy infrastructure such as onshore wind, solar plants or transmission lines. Moreover, depending on the nature of the governance system, local variation in public acceptance may either enable or restrict policy adoption in federal multilevel governance systems [4, 5].

In this paper, we estimate local opinion towards 26 climate change mitigation policies from the energy, transport, and building sector across all 402 German counties (NUTS3 level). To this end, we use two large nationally representative panel studies conducted between 2017 and 2021 and employ small-area estimation based on multilevel regression and poststratification (MRP). To our knowledge, we are the first to conduct such an analysis for a large suite of different policies. Moreover, building on prior work that has used MRP to estimate geographic variation in climate change opinions [6–8], we also explicitly model year-by-year variation in policy support and provide estimates for each policy for each year in our data set. This enables us to track how geographic patterns of policy support vary across the five-year survey period. Germany is a relevant case as it has already implemented several climate policies in all relevant sectors (electricity, transport, and heating) and is actively discussing the implementation of more instruments including ratcheting up national carbon pricing (which was introduced in Germany in 2021), phasing out fossil heating, and restricting fossil fuel use in transport [9].

Our results suggest that on average pull instruments, like subsidies for the adoption of electric vehicles, tend to be popular, while push instruments, like taxes and bans, receive less support. However, the

support of instruments can vary by as much as 60 percentage points across regions. We observe particularly large disparities for the phase-out of coal and carbon pricing, which are cornerstones in Germany's climate policy. Exploiting the regional variation further, we detect that there are large differences in the support rates between urban and rural participants as well as between residents of East and West Germany. In turn, exploiting the temporal variation of our data, we find that for some policies, such as the construction of onshore wind farms, support has converged. However, for other instruments support has diverged spatially, resulting in a polarized country. Finally, using a spatial regression framework, we demonstrate that local support hinges on spatial diffusion.

2. Methods

2.1. Survey data

We use survey data from two large national panel studies from Germany. Participants of both studies were randomly selected from the broader nationally representative household panel *forsa.omninet,* which comprises about 100.000 respondents. The data for the support of policies in the power and transport domain are drawn from the Social Sustainability Barometer, an ongoing online panel survey assessing attitudes, preferences, and evaluations of the German population regarding the energy and transport transitions in Germany [10, 11]. The national survey was administered by the market research institute *forsa* in four waves annually from 2017 to 2019 and 2021 during the following periods: July in 2017 (wave 1), August to September in 2018 (wave 2), November in 2019 (wave 3), and March to April in 2021 (wave 4). In the first wave a total of $n = 7{,}843$ household heads aged between 18 and 92 years participated, followed by $n = 6{,}549$ respondents in the second and $n = 6{,}189$ in the third wave. In 2021 a new sample was drawn comprising $n = 6{,}822$ respondents, representative for the general German population. In turn, support on policies in the heating domain were elicited in 2021, drawing on data that was gathered in the framework of the Kopernikus project Ariadne (n = 15,426). The survey was conducted between July 23 and September 2, 2021 also in collaboration with *forsa*. Additional survey details and information on additional data sources as well as data processing are provided in the supplementary materials.

Our outcome variables are measured on five-point Likert scale ranging from 'I do not support' to 'I fully support'. For our purposes, we dichotomize the survey responses and consider individuals as supportive for a certain policy or policy goal if they are 'at least somewhat supportive' of this policy or policy goal, that is, reporting a four or a five on the respective scale. We use age, gender, and education to match individual with census level information for the poststratification during the MRP procedure. For some individuals, information on education (or less frequently age) is missing. Since we cannot assume that this information is missing completely at random, we use a machine-learning enhance multiple imputation technique to impute education based on a large number of individual-level variables collected in the surveys [12, 13]. For the census level information, we use data from 2011, which is the most recent census level information available [14].

2.2. Local area estimation

Locally representative estimates of political opinion are difficult to obtain as most surveys are only representative at the national level. Using simple sample means to approximate average local opinion is misleading as the small number observations in the local sample means that random deviation can lead to severe difference between sample and population mean at the local level. Here, we use a machine-learning infused multi-level and poststratification method (MRP) to approximate the population mean climate change policy acceptance among 402 German Landkreise (equivalent to counties) and cities.

The MRP procedure [15] (see section 2 in the methods section for more details) disaggregates the population across a large number of socio-demographic categories and estimates opinion for each category in each local area (for more applications, see [16–19]). Poststratification using census information is then used to aggregate estimates based on the population of each socio-demographic category within each local area to create locally representative figures that are not directly observed. We estimate this model with a new ensemble classifier that is fitted through Bayesian model average. Besides using a classical multilevel regression model, we also consider four machine learning classifiers: *principle components analysis, lasso regression, gradient tree boosting*, and a *support vector machine*. Recent research has shown that this ensemble method can increase the accuracy of MRP methods by up to 20% [20]. The multi-level modelling and poststratification analysis was executed with the R package autoMrP on a high-performance computer using 128 processor cores.

2.3. Spatial panel regression

To explore the relation of a range of independent variable on local support of climate change mitigation policies, we calculate a spatial fixed effect model. In particular, we test how changes in population size, unemployment share, voting results, and generation capacities relate to changes in climate policy support. See supplementary material for additional details.

3. Results

In this section, we first analyze support for cross-sectoral climate policies and subsequently climate

policy specific to different sectors such as power, transport, and heating. For each policy, we estimate spatial differences in supporting that policy at a given point of time (figure 1), but also changes of support across time (figure 2). The latter analysis allows us to establish where support converges and where it diverges, which we illustrate in figure 3. The data used for this analysis is available in the supplementary data. In addition, we present the results of a spatial regression that identifies the temporal difference in support rates based on local characteristics.

For the sake of conciseness, in this paper we focus our analysis on the main climate policies and those with the most striking developments. We present results for all 26 climate change measures in a dashboard that we have developed to accompany this paper that provides a graphical illustration of our results (https://hertie-school-ariadne.shinyapps.io/LocalAttitudesDashboard/). While we focus here on the differences at the county level, the dashboard also presents results across Germany at other subnational scales such as state and local levels (provided there is sufficient data in the surveys, which is mostly the case for large cities and counties with more than 10,000 inhabitants).

3.1. Regional support for climate policy

We find climate policy support to vary strongly across both policy domains and regions. Consistent with other research [21], we generally find a high degree of support for pull measures that subsidize or facilitate the use of clean energy technology (i.e. expansion of bike infrastructure and public transport). Policies that restrict the use of fossil fuels, such as carbon pricing, bans of fossil fuel heat boilers, or a phase-out of fossil fuel cars are supported much less (see figure 1).

We observe two broader trends regarding the regional variation of climate policy support. First, climate policies tend to be much more supported in urban areas than in rural areas. In particular, the cities of *Berlin*, *Hamburg*, and *Munich* are areas with the highest degree of support across most policies. This finding is consistent with other studies that find people living in urban areas to be more likely to believe in climate change and to be more worried about it [7, 8, 22, 23]. Carbon pricing, which is the cornerstone of Germany's climate policy, is supported by 60% of those living in cities with more than 500 000 inhabitants compared to approximately 50% in all other places (figure 1(f)). Another key climate policy is the phase-out of coal power, which has greater than 80% support in Germany's largest cities, such as *Berlin*, *Hamburg*, and *Munich*, but much less in rural areas (figure 1(c)).

Targeting the transport sector tend to be less popular. When asked about a ban on new registrations of passenger cars with gasoline or diesel engines from 2030, support is below 25% in the majority of cities and counties (figure 1(e)). Yet, there is a very clear urban-rural divide since we observe by far the highest support in *Berlin* (56%), followed by *Hamburg* (45%) and *Cologne* (44%). Analogously, support for potential policies in the heating sector, such as a levy on the emissions from buildings (figure 1(b)) and a ban of new gas-fired furnaces (figure 1(d)), is much higher in urban areas compared to rural areas.

The only exception to this pattern is the support for the expansion of bike infrastructure (figure 1(a)), which fewer respondents in major cities in Berlin (60%) and Hamburg (56%) support compared to the German average across all counties (73%). This may be due to space availability in these metropolitan areas. However, regarding this policy, overall support in Germany is high across all counties [8, 22, 23].

Second, we detect that residents of East Germany are less supportive of many climate policies compared to the German average across all counties. For example, around 40% of the respondents living in East Germany counties indicate a willingness to pay higher prices for fossil fuel for climate mitigation, compared to 54% of those living in counties from former West Germany. More specifically, support for carbon pricing is as low as 30% in some East German counties and as high as 72% in *Munich*. Regarding the phase-out of fossil-based cars, in many western German cities, support exceeds 30%, while it is below 20% in most East German counties. Even though support is relatively low outside metropolitan areas, there is a slight east-west divide since the 85 counties with the lowest support rates are mainly found in East Germany (e.g. *Spree-Neiße* with 18%). The disparity between East and West Germany is particularly large for the phasing out of coal combustion for power generation (figure 1(c)). Only *Berlin* stands out in East Germany, exhibiting one of the highest support rates of all Germany. However, support in most East German counties is below 50%.

The difference in climate change attitudes among Germans living in Eastern and Western Germany could result from a more widespread sense of being left behind in Eastern Germany, which fuels skepticism towards the seemingly complex and cosmopolitan topic of climate change [24, 25]. Moreover, it could also be a legacy from the former autocratic political regime of the German Democratic Republic, which suppressed any environmental activism and which has strong lagged effects of climate change concern among its former citizens [26].

3.2. Temporal evolution of support for climate policy

Besides establishing cross-sectional variation, we calculate year-specific estimates for local attitudes on climate change mitigation policies for which we have individual-level survey data from three or more years. Figure 2 illustrates how local support for the expansion of onshore wind power plants as well as solar power plants, the phase-out of coal combustion, and

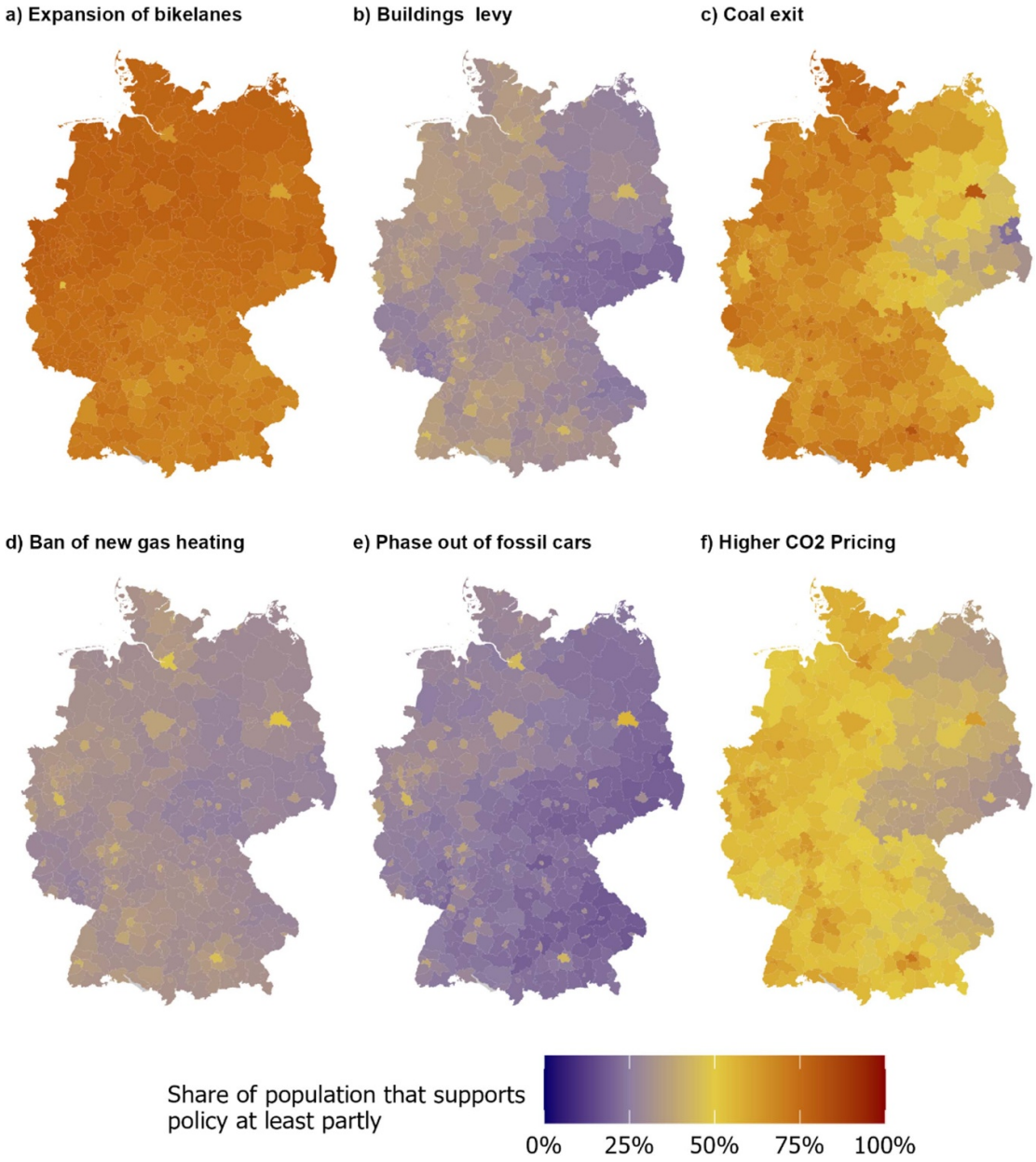

Figure 1. Local variation in climate change policy opinion. Share of respondents that are at least somewhat supportive of (a) expanding bike infrastructure (2021), (b) carbon-based building levy for homeowners (2021), (c) phasing out coal-fired electricity generation (2019), (d) phasing out gas fired heat boilers (2021), (e) phase out registration of cars with internal combustion engine until 2030 (2021), and (f) paying higher prices for fossil fuel such as heating oils or natural gas to contribute to climate protection (2019).

of fossil cars has changed between 2017 and 2021. Figure 3 visualizes the relative changes in each unit and point of time for these four policies.

Average local support (i.e. across all counties) for the expansion of solar power plants increased by 16 points from 58 percentage points in 2018 to 74 points in 2021 (figure 3(d)). Policy support has increased uniformly across all counties, with the range of observed values increasing from 52%–64% in 2018 to 70%–83% in 2021. The increase in support was strongest in counties where support was low in 2018, mostly in Germany's East and South. In some of these counties, the support increased by around 30 percentage points, leading to an overall convergence of policy support at a higher level (the standard deviation decreased from four in 2018 to three percentage points in 2021).

We find similar patterns for the local support of expanding onshore wind power plants, as it increased substantially by 26 percentage points from 49% in 2017 to 75% in 2021 (see figure 2(a)). For example, average support across all counties for the expansion of onshore wind power plants increased by almost 25 percentage points from 33% in 2017 to 58% in 2018 in the Landkreis *Mecklenburgische Seenplatte*. Factors contributing to the strong increase in these county and neighboring counties could be the financial compensation policies introduced

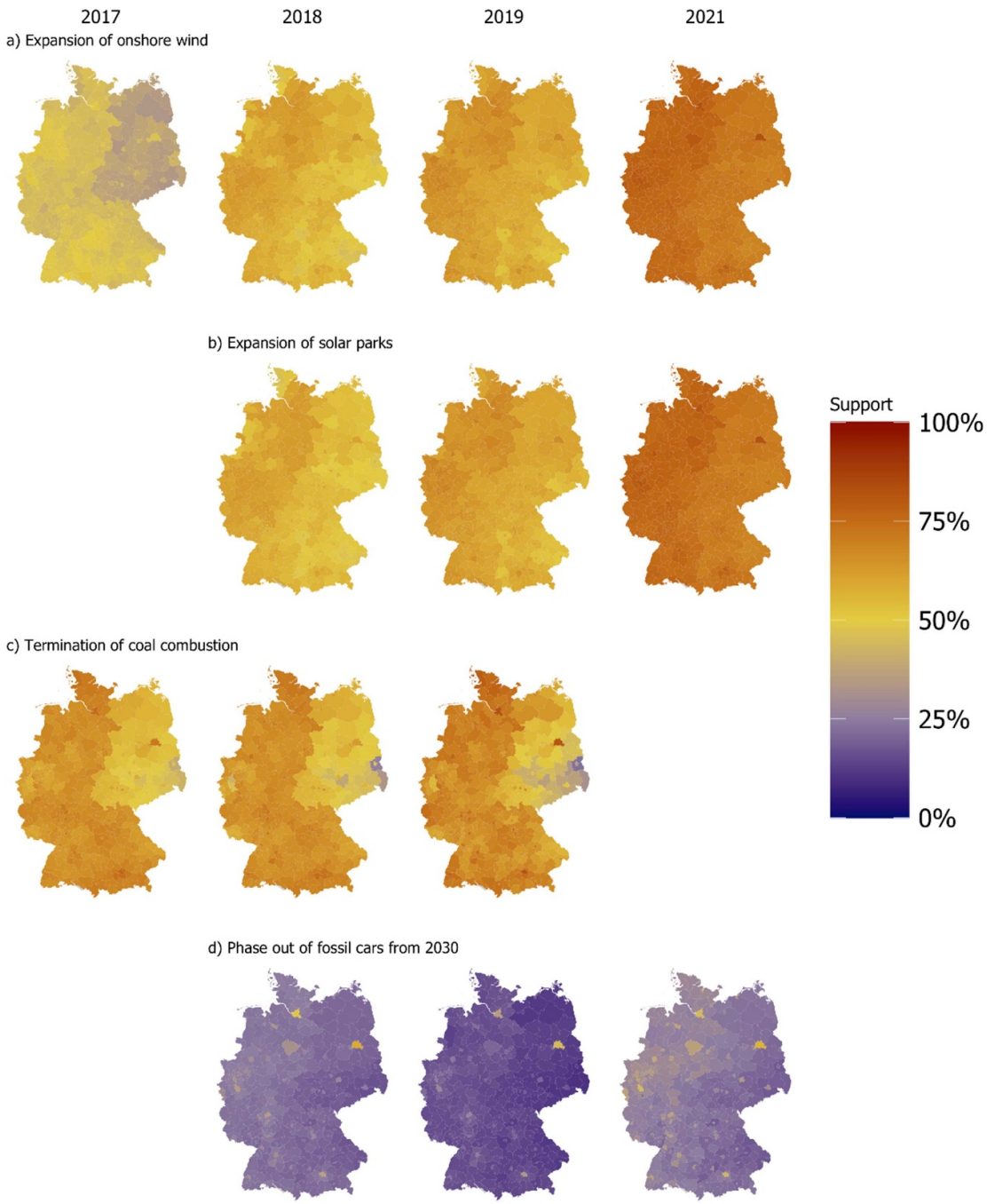

Figure 2. Year specific local climate change attitudes. Share of respondents that are at least partially supportive of (a) expansion of onshore wind plants (2017–2019, 2021), (b) expansion of solar parks (2018–2019, 2021), (c) phase out of coal firing (2017–2019), and (d) phase out of fossil cars (2018–2019, 2021) for 2017, 2018, 2019, and 2021. Blank areas indicate years where survey data are unavailable for each question.

in *Mecklenburg Vorpommern* and *Brandenburg*, after which profit from wind power generation must be shared with local communities.

More generally, public support for onshore wind power plants, which was far below 25% in large areas of East Germany has increased strongly over the last five years and is now far above 50% in all counties. This increase has been driven primarily by a largely uniform increase in all units (see figure 3(a)). We also observe a convergence at a higher mean, as the standard deviation of supporting this policy decreases from four to 2.8 percentage points between 2017 and 2021. This convergence may be driven by a saturation effect: Since support was already very high at the outset, there is limited scope for further increases in support.

Contrary to attitudes towards wind and solar power, we observe that average local support across all counties for the phaseout of coal combustion for power generation fluctuates around 65% between 2017 and 2019 and thus stagnates. In addition, we detect a divergence and polarization in local support, as the standard deviation of support increases

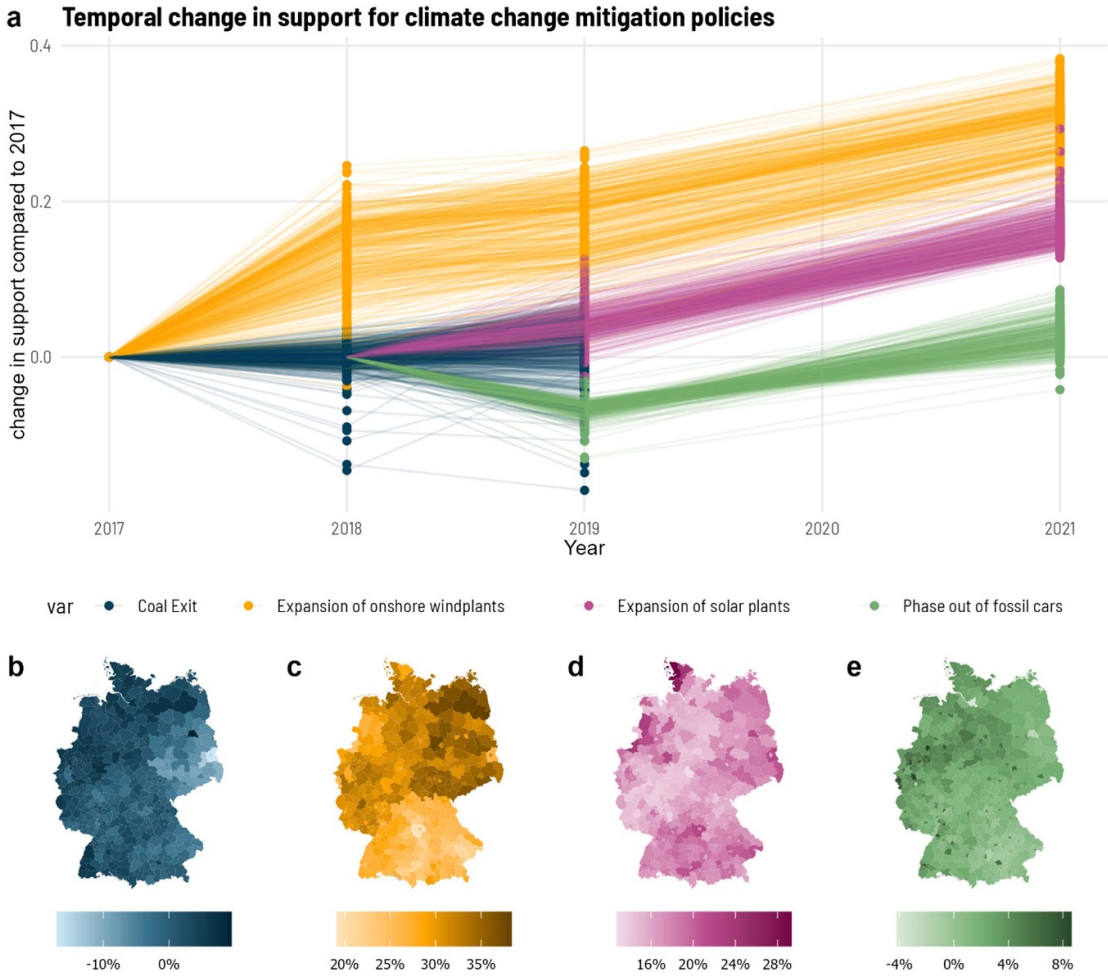

Figure 3. Temporal change in local climate change policy support. Difference of policy support compared to the year 2017, per year (a) and spatially disaggregated (b)–(d).

from 5.8 percentage points in 2017 to 8.5 in 2019 (figure 3). For instance, support increased by almost 10% in Berlin but decreased by 17% in the *Spree-Neiße-Kreis*, a rural county in former Eastern Germany with energy-intensive industry and a right-wing populist majority. We detect the same pattern in some West German counties that exhibit a large industrial sector.

Likewise, support for the phase-out of fossil cars also started to polarize across German counties (figure 3). Average levels of local support for the phase-out of fossil cars first decreased from 26% in 2018 to 16% in 2019 and increased again to 30% in 2021. However, over that time period local support started to polarize across counties, as the standard deviation increased from 3.6 percentage points in 2018 to 4.7 in 2021. This increasing polarization was primarily driven by substantial increases in support in Germany's urban areas, while opinion remained mostly unchanged in the rural areas. The increased level of polarization might be due to an intensified debate about climate change protection measures and environmental restrictions for fossil cars. During this period, various countries have introduced a ban for vehicles with an internal combustion engine (e.g. Denmark, Norway, Sweden). The German government announced its climate protection package in 2019, and debates around it particularly problematized the transport sector as it is Germany's only sector that has not reduced emissions since 1990—with fossil cars being responsible for the bulk of the emissions. At the same time, several German cities including *Hamburg*, *Frankfurt*, and *Stuttgart*, implemented driving bans on older diesel vehicles to combat air pollution. Public discussions centered around the effectiveness of these bans and the need for alternative transportation options for people who relied on older diesel cars. This may have further induced controversy for the support of phase out of fossil cars in Germany that year.

3.3. Spatial regression results

As a next step, we use a spatial panel regression to estimate and better understand the impact of changes in contextual factors on the development of

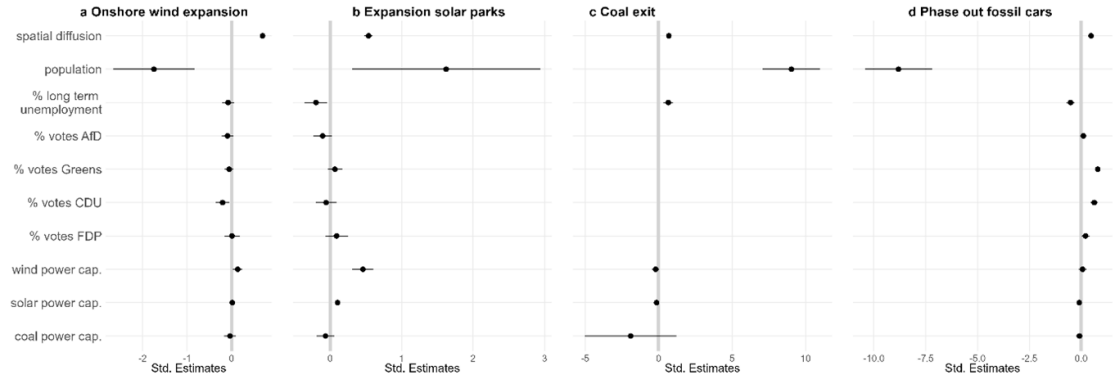

Figure 4. Regression results. Standardized regression coefficients from a spatial panel analysis to explain changes in local support for (a) expansion onshore wind plants, (b) expansion of solar parks, (c) phase-out of coal combustion, (d) phase out of fossil cars. Coefficients are standardized and error bars represent 95% confidence intervals.

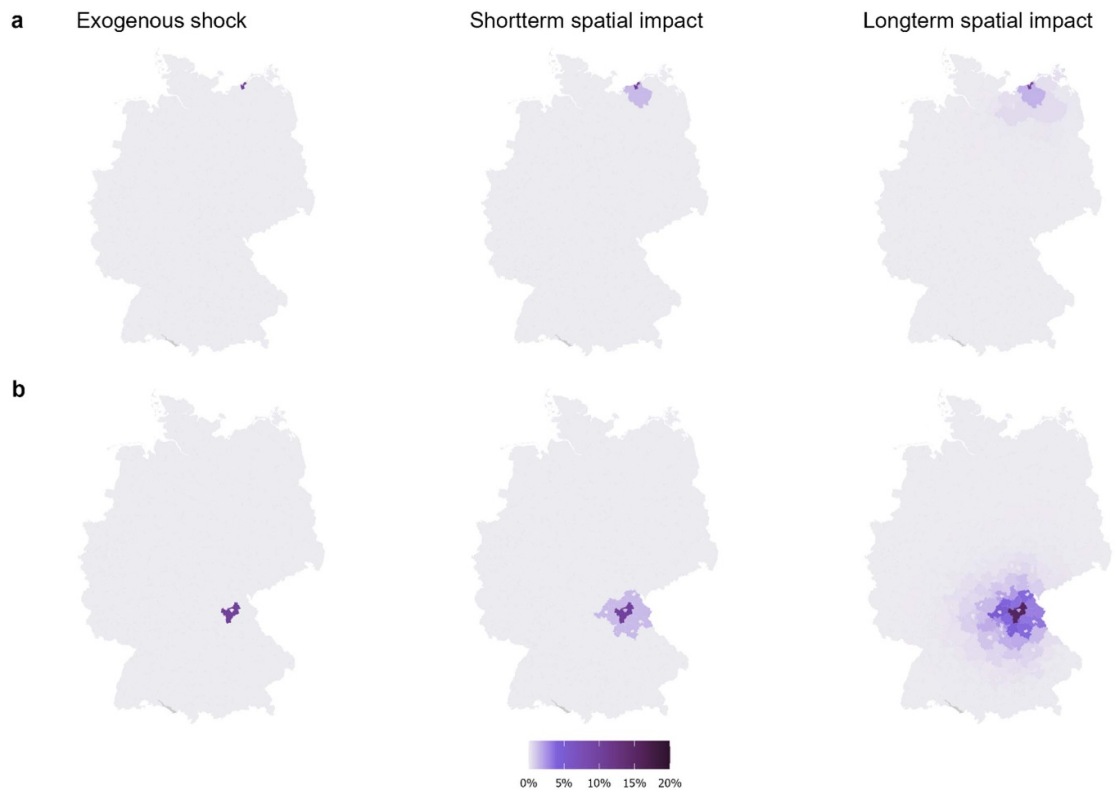

Figure 5. Simulated spatial impact for a remote region, Rostock (a), and a well-connected region, Bayreuth (b).

local support for climate policies (see supplementary material for the details on the method). We find that changes in population size predict changes in support for climate policies, albeit in different directions (figure 4). Regions where population increased over time became more supportive of phasing-out coal and of expanding solar parks, but less supportive of banning fossil cars and building onshore wind plants. Moreover, we detect that increases in unemployment predict a higher support for the phase out of coal combustion, but less support for solar parks and phase out of fossil cars.

In addition, we find that changes in political preferences predict changes in climate policy support. Increases in votes for either the green, conservative (CDU) or liberal (FDP) party are associated with higher support for a phase-out of fossil cars. Moreover, a higher share of votes for the conservative party are associated with a decrease in local support for wind power parks. Likewise, increases in capacity of both wind power plants and solar plants are correlated with increases in support for solar power plants in that region. These observations are consistent with longitudinal studies finding that acceptance of wind power increases after they are constructed [27, 28].

Changes in capacities of solar power plants were also negatively correlated with local support for phase out of coal.

We also find a strong and highly significant positive spatial correlation, using a simple representation of proximity based on county contiguity. This means that changes in support for climate policies in one unit have a positive influence on the development of the support for these policies in neighboring regions. Similar diffusion patterns have also been observed for other environmental attitudes and behaviors and are likely transmitted through communication in relational and community networks as well as elite cues from local opinion leaders [29, 30].

Because positive spatial diffusion is the significant and most consistent predictor of climate policy support, we analyze this predictor in more detail (see section 2 of methods for more details). For the sake of better interpretability and contextualization of the estimated spatial impact, we use our model to calculate the spatial impact from a hypothetical exogenous shock on local support for onshore wind power in two regions—first *Rostock*, a city that is not well connected to other counties (i.e. with few neighbors) and second *Bayreuth*, a region that is very well connected to other counties (i.e. with many neighbors). The exogenous shock could be a climate change related protest event, a local climate impact, or a policy that increases acceptance of wind power plants, for example by redistributing the plant's profit to the community.

Figure 5 displays the exogenous shock and the short-term spatial impact which includes the shock itself and the resulting first-level spatial spillover that the model predicts to be created by this event in neighboring counties. It also displays the long-term spatial impact, which the equilibrium impact that is theoretically approximated after infinite rounds of (increasingly diminishing) spillovers and their feedback effects. Our model results show that both the short-term spatial impact as well as the long-term spatial impact are substantially higher in a well-connected region like *Bayreuth* (contiguous with many other counties) than in a more isolated region as *Rostock* (contiguous with only one county).

4. Conclusion

In this analysis, we have contrasted the support for a variety of climate policies across space and time in Germany based on two large surveys spanning the period from 2017 to 2021. We find substantial local variation in support for climate policies across Germany. Especially for some policies like the phase-out of coal combustion, level of support varies by almost 60 percentage points across regions. We observe similar divergence between urban and rural areas to previous work in the United States and Canada. Building on previous work which typically only models climate change opinion for a single year, we model and map changes in opinion over a time and observed both convergence as well as divergence processes to take place between 2017 and 2021, depending on the policy question.

From a political perspective, it is particularly consequential that average support across all counties for most climate policies has increased over time. This facilitates implementation of climate policies, as less resistance from the population is to be expected. However, support has by no means risen uniformly. For example, we observe a geographic convergence for some climate policies, such as the expansion of onshore wind power plants and solar installations. In regions where approval for the expansion of these generation technologies was relatively low at the beginning of the observation periods, approval has thus grown particularly strongly. On the other hand, the increase in regions with already high approval has necessarily been less intensive.

In contrast, we observe a pronounced divergence in the approval of the coal phase-out: While support has risen in regions with high approval rates, support has declined in some regions with low support rates. From a policy perspective, this is a challenging development, as resistance to the policy could increase at the local level as polarization increases. However, policymakers can try to use targeted information and communication campaigns to promote local approval of policies needed to prevent climate change and, for example, make dialogues region-specific.

While average support for measures in the electricity sector are relatively high, support for measures in the transport sector are often rather low. For example, 26% of our participants support a ban on internal combustion cars. Against the backdrop that all sectors must make a significant contribution in order to achieve climate targets, greater resistance among the population can therefore be expected in the transport sector.

In our regression analysis we found that the development of local policy support is strongly influenced by spatial diffusion, a phenomenon that is highly significant across all policies. Our model finds the spatial diffusion to be strongly dependent on the connectivity of regions with each other. While we have defined proximity between regions as spatial contiguity, connection may also be based on social networks within employees with an organization, members of an association, or friendship ties. Future research should further investigate which type of connectivity influences the spread of climate change opinion. This kind of research may be of crucial value for decision makers and advocacy groups who need to decide in which places to conduct communication interventions.

More research is needed to establish under which conditions public opinion on climate policies converges across regions and when views polarize. We contribute to this line of research by sharing our data and code. This will allow researchers to further explore and analyze the development of local support for climate change policies more extensively.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

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