

Supplementary Information

Common Response, Unequal Vulnerability: Heat and Residential Electricity Demand Across Chinese Cities

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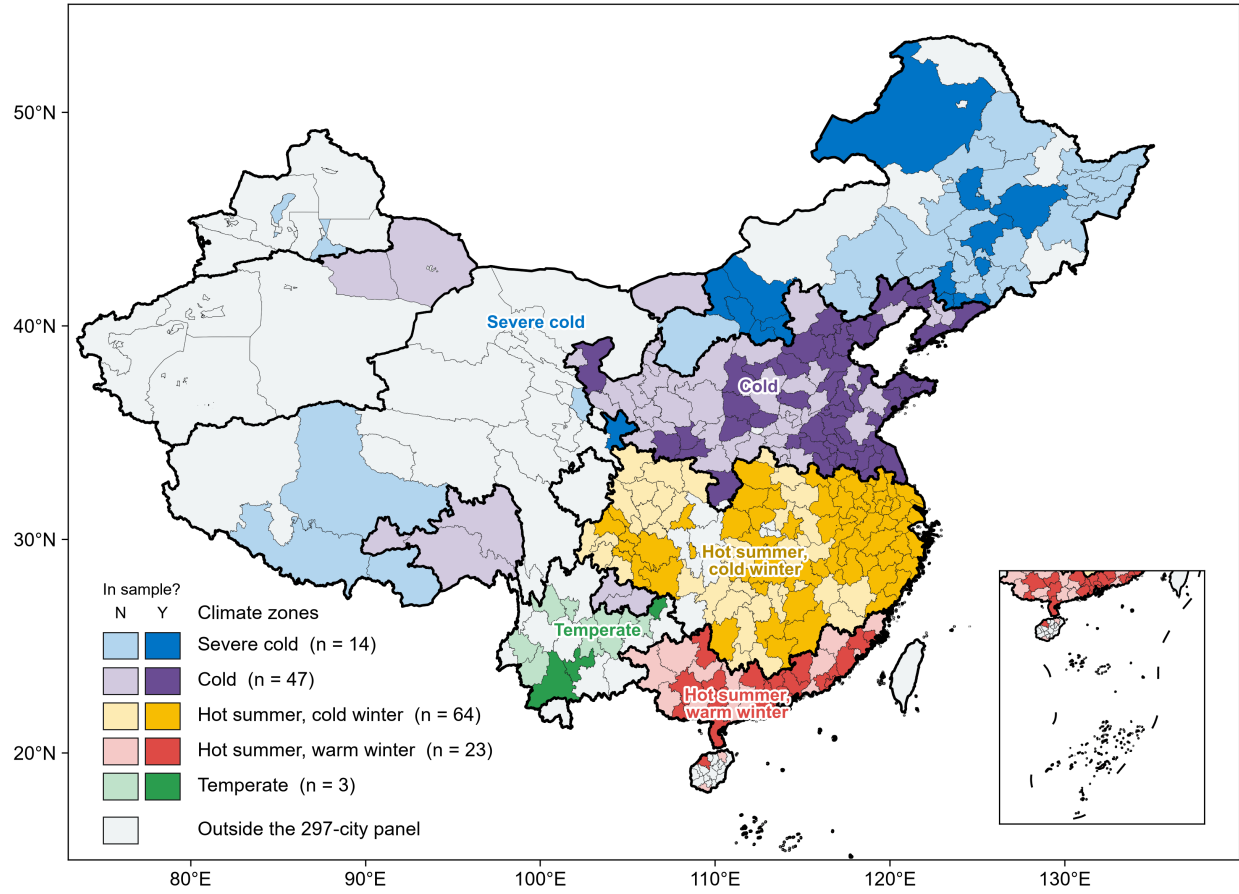


Fig. S1 | Estimation sample and climate zones of China. The 151 sample cities are shown as filled polygons coloured by climate zone (Ministry of Housing and Urban-Rural Development of the People's Republic of China, 2016).

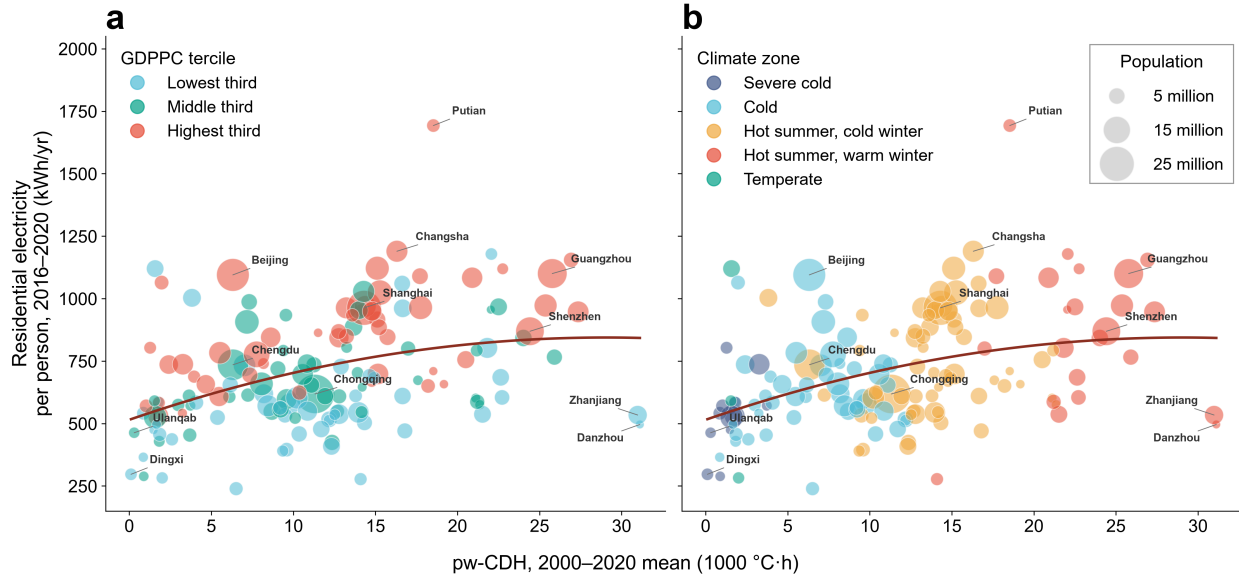


Fig. S2 | Heat exposure and residential electricity per capita across the 151 estimation sample cities. Each bubble is one city, positioned by its 2000 to 2020 mean pw-CDH (x axis) and 2016 to 2020 mean residential electricity per person (y axis), with area proportional to population. **a**, Cities coloured by real GDPPC tertile. **b**, Cities coloured by climate zone. Labelled cities are the six most populous and selected cities near the edges of the scatter.

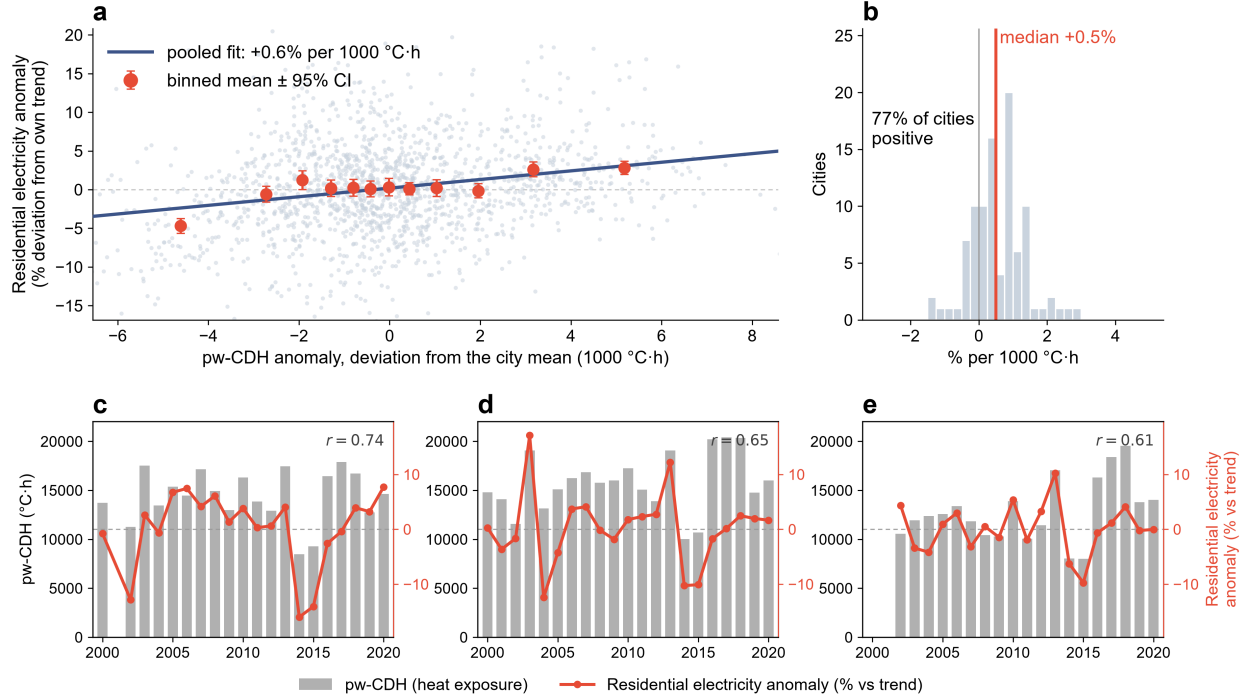


Fig. S3 | Year-to-year weather signal in residential electricity, 2000 to 2020. The electricity anomaly is the percentage deviation from a city-specific quadratic trend in log electricity, removing long-term growth to isolate the weather response. **a**, Pooled scatter for 95 cities: grey dots are city-years, red markers are binned means with 95% confidence intervals, and the line is the pooled fit. **b**, Distribution of city-level slopes, with the median marked. **c–e**, Three individual cities (**c**, Shanghai, **d**, Jiaxing, **e**, Yangzhou) showing annual pw-CDH (grey bars) and the electricity anomaly (red line), with r being the correlation between them. Trends are fitted within each reporting segment, requiring at least twelve reporting years, which restricts the figure to 95 of the 151 sample cities (1,618 city years). The regressions use the full unbalanced panel. The three cities are those with the strongest pw-CDH correlation among cities reporting for at least nineteen years with no year-on-year electricity change above 30%.

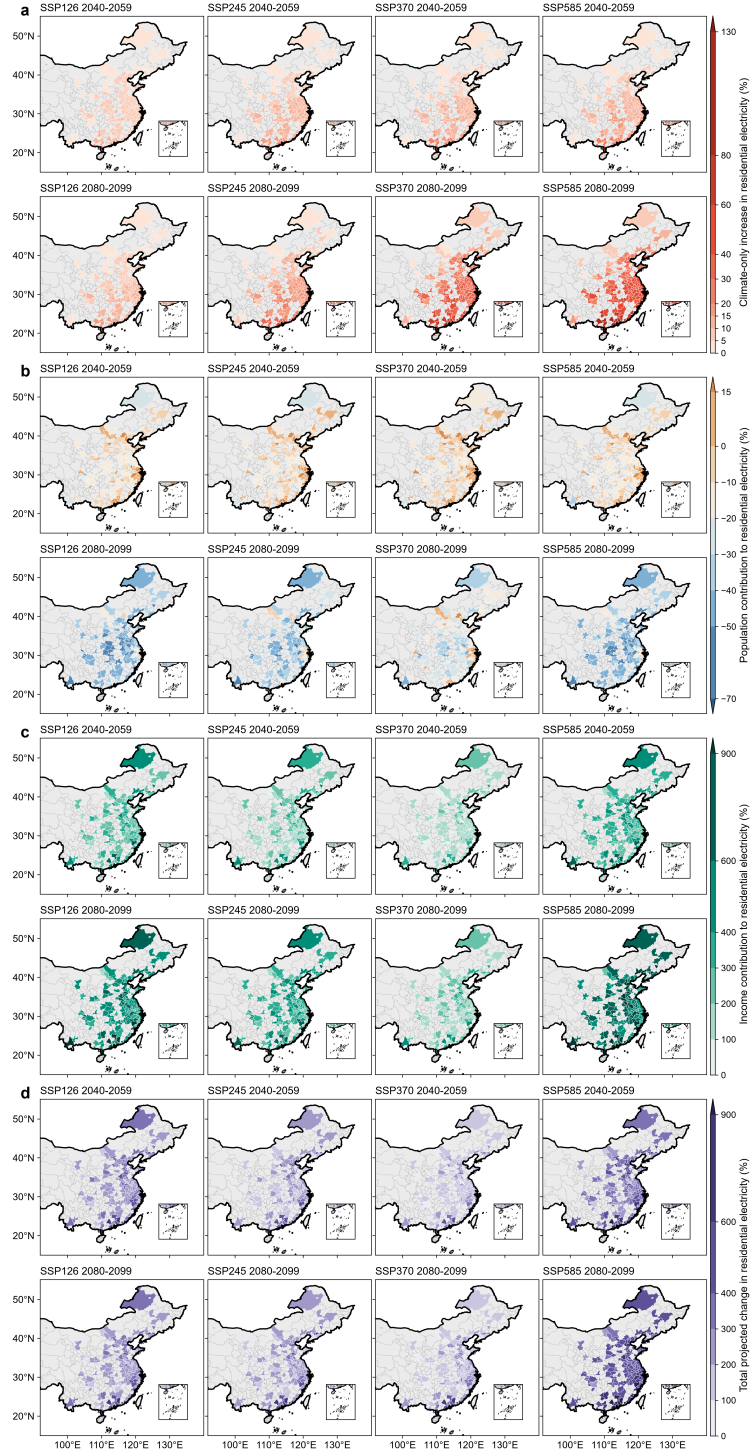


Fig. S4 | City-level projected changes by driver under four SSP scenarios (columns) and two time periods (rows: mid-future 2040–2059, far-future 2080–2099). From top to bottom: **a**, climate-only increase in residential electricity demand. **b**, population change. **c**, GDP growth. **d**, total change from all three drivers combined. Maps are cropped to east of 92°E, west of which no sample city lies.

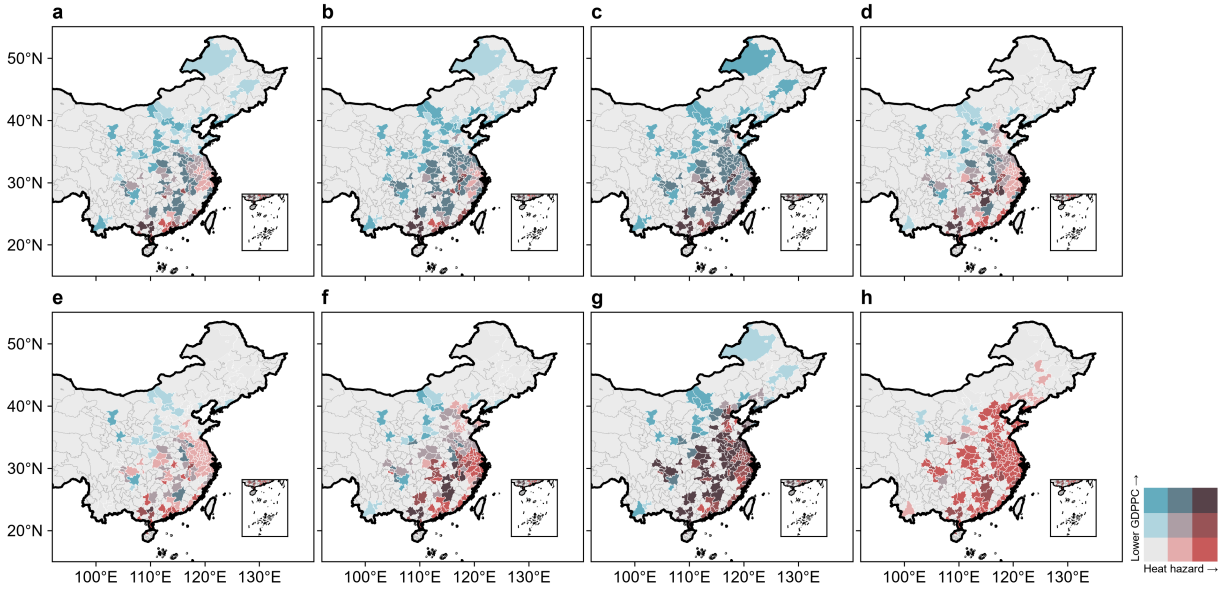


Fig. S5 | City-level heat hazard and adaptive capacity under four SSP scenarios and two time periods. **a–d**, Mid-future (2040–2059). **e–h**, far-future (2080–2099), each ordered SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP5-8.5 left to right. Each sample city is coloured by a bivariate scheme (legend in panel **h**): the horizontal axis is heat hazard (terciles of the estimated electricity rise from pw-CDH, pooled over the baseline and all futures) and the vertical axis is lack of adaptive capacity (terciles of GDPPC pooled over all scenarios and periods, poorer upward). Cities outside the sample are light grey. Maps are cropped to east of 92°E, west of which no sample city lies.

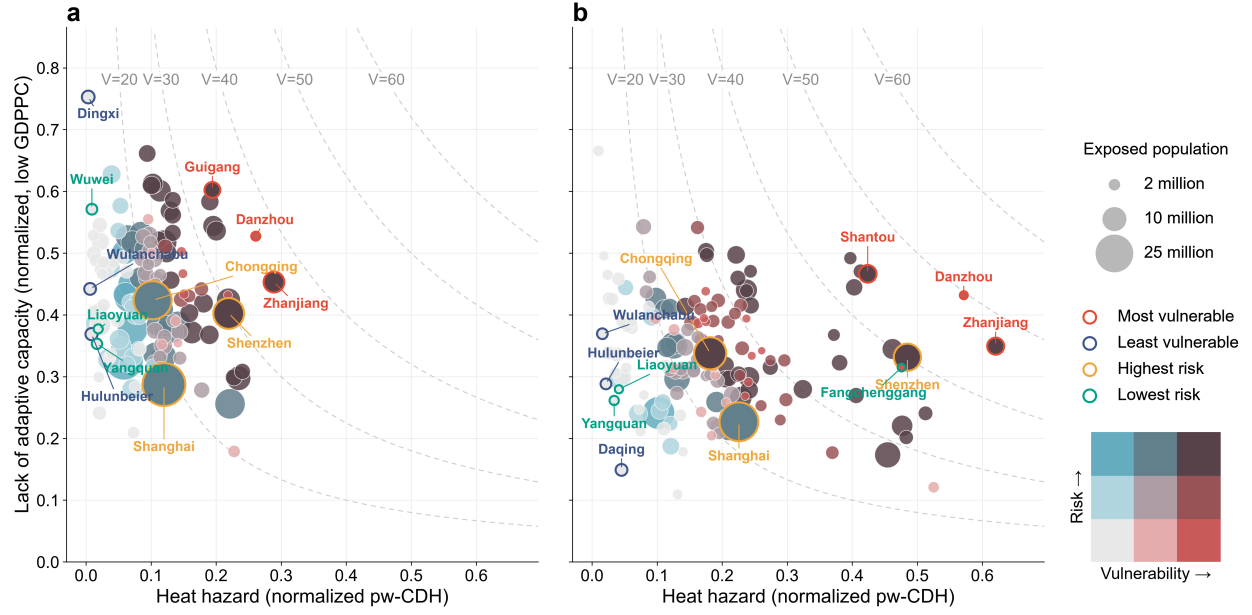


Fig. S6 | Heat hazard against lack of adaptive capacity for every sample city. **a**, Mid-future (2040–2059). **b**, far-future (2080–2099). Both axes are min-max normalized components of the vulnerability index, and dashed curves join points of equal index value. Marker area is the exposed population, so position and size together convey both the vulnerability and risk indices. Values are means across the four pathways within each time period. Cities are filled by a bivariate scheme with vulnerability increasing along the horizontal legend axis and risk increasing upward, each cut at terciles pooled over both periods. The three most and least vulnerable and the three highest- and lowest-risk cities are outlined and named in each panel.

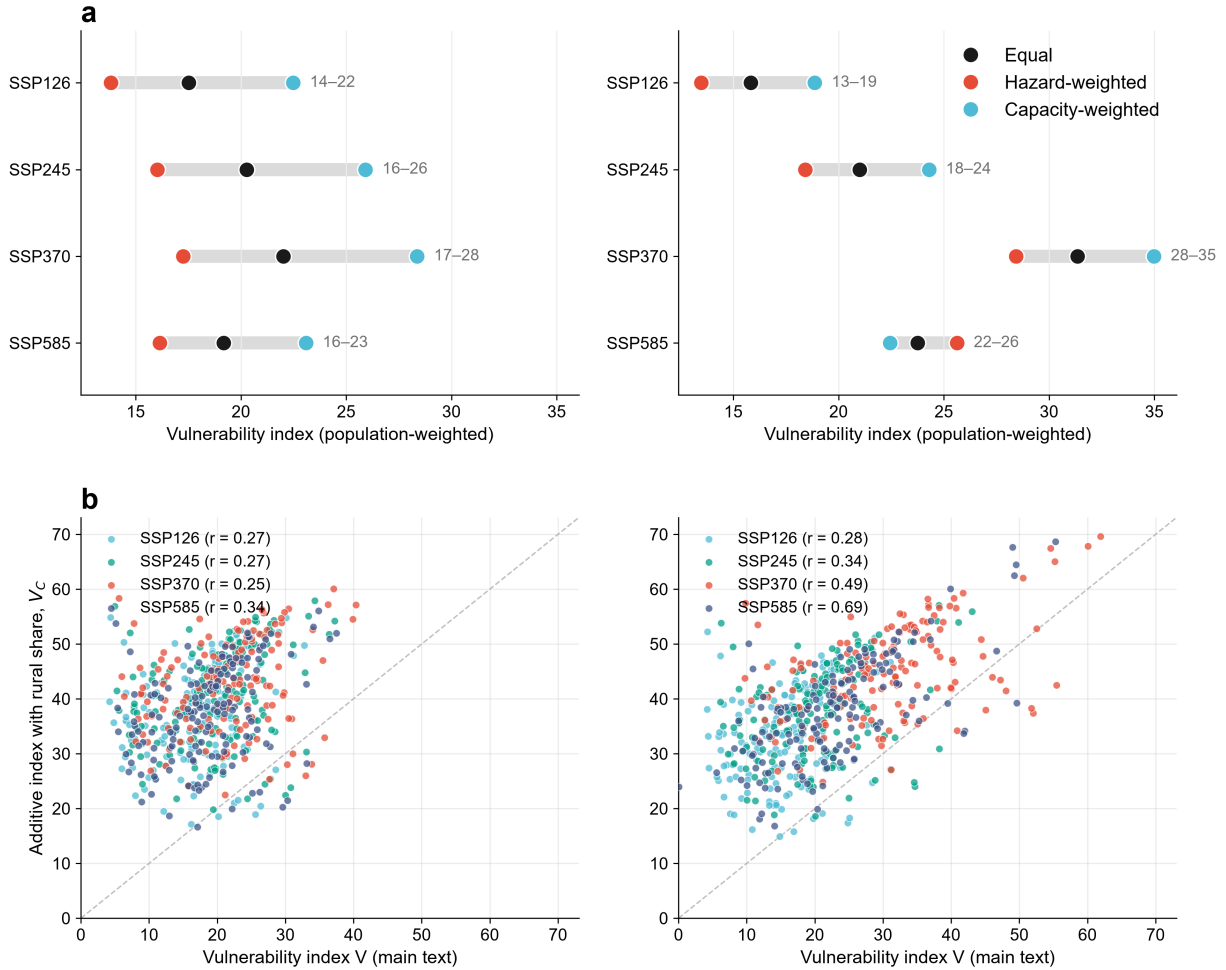


Fig. S7 | Vulnerability index robustness checks. **a**, Population-weighted vulnerability index under three weighting schemes, by scenario and time period, with mid-future (2040–2059) on the left and far-future (2080–2099) on the right. Each scheme doubles the weight on one component (hazard or adaptive capacity) relative to equal weighting. The grey bar spans the three schemes and the dots are the individual schemes. Scenarios run from SSP1-2.6 (top) to SSP5-8.5 (bottom). **b**, Main vulnerability index against an additive Notre Dame Global Adaptation Initiative (ND-GAIN)-style alternative that includes the rural population share, with mid-future on the left and far-future on the right. Each dot is one of the 151 sample cities under one scenario, coloured by scenario. The city-level Pearson correlation between the two indices is shown for each scenario.

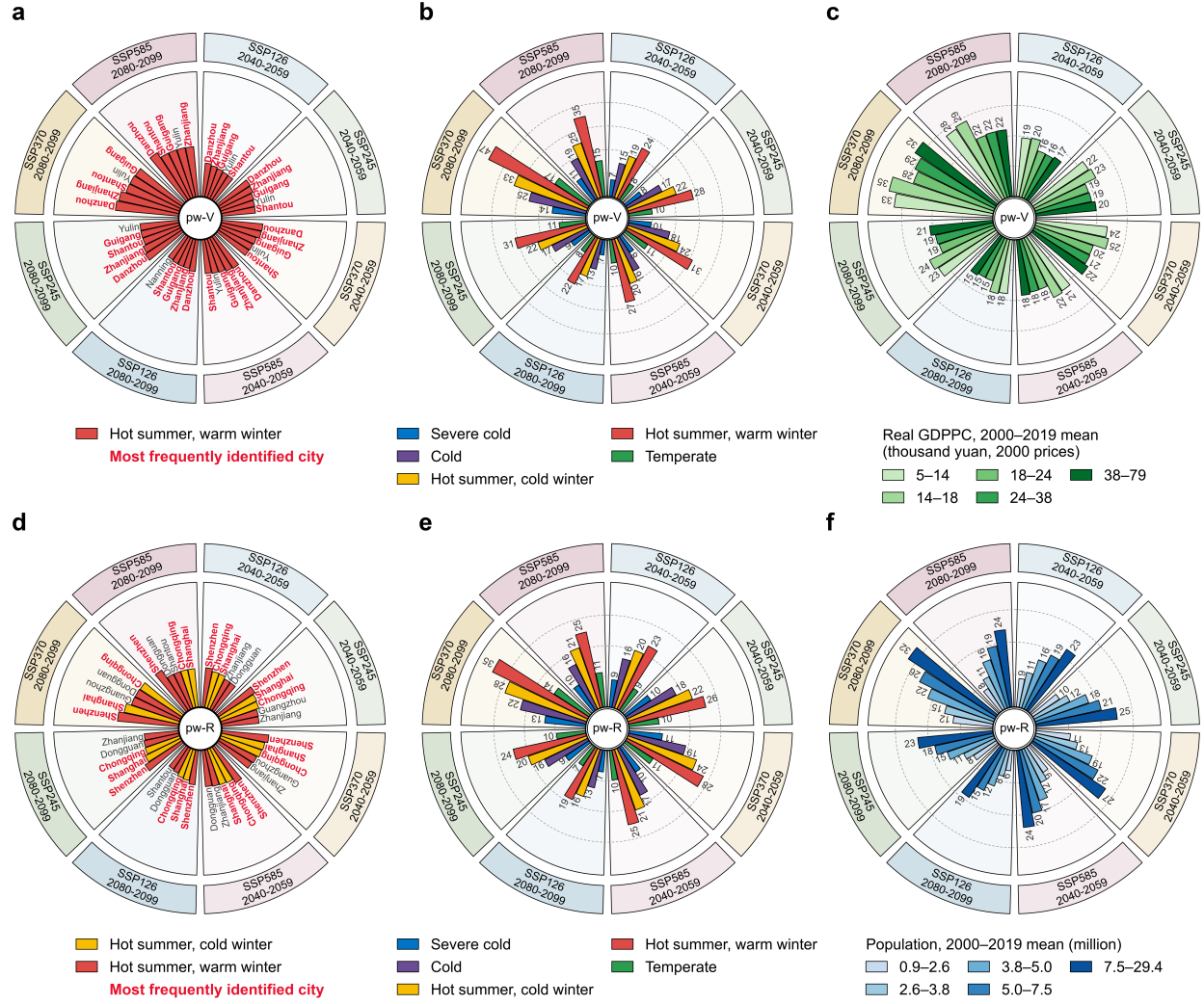


Fig. S8 | Population-weighted vulnerability and risk indices by scenario and time period. Each sector shows one scenario-period combination. Top row: vulnerability index, with **a**, the five most vulnerable cities, coloured by climate zone. **b**, five climate zones. **c**, five income quintiles. Bottom row: risk index, with **d**, the five highest-risk cities. **e**, five climate zones. **f**, five population quintiles. Income and population quintiles are defined by 2000–2019 baseline means and held fixed across scenarios. Bar length is the population-weighted mean index of each group, or the city's own index in **a** and **d**.

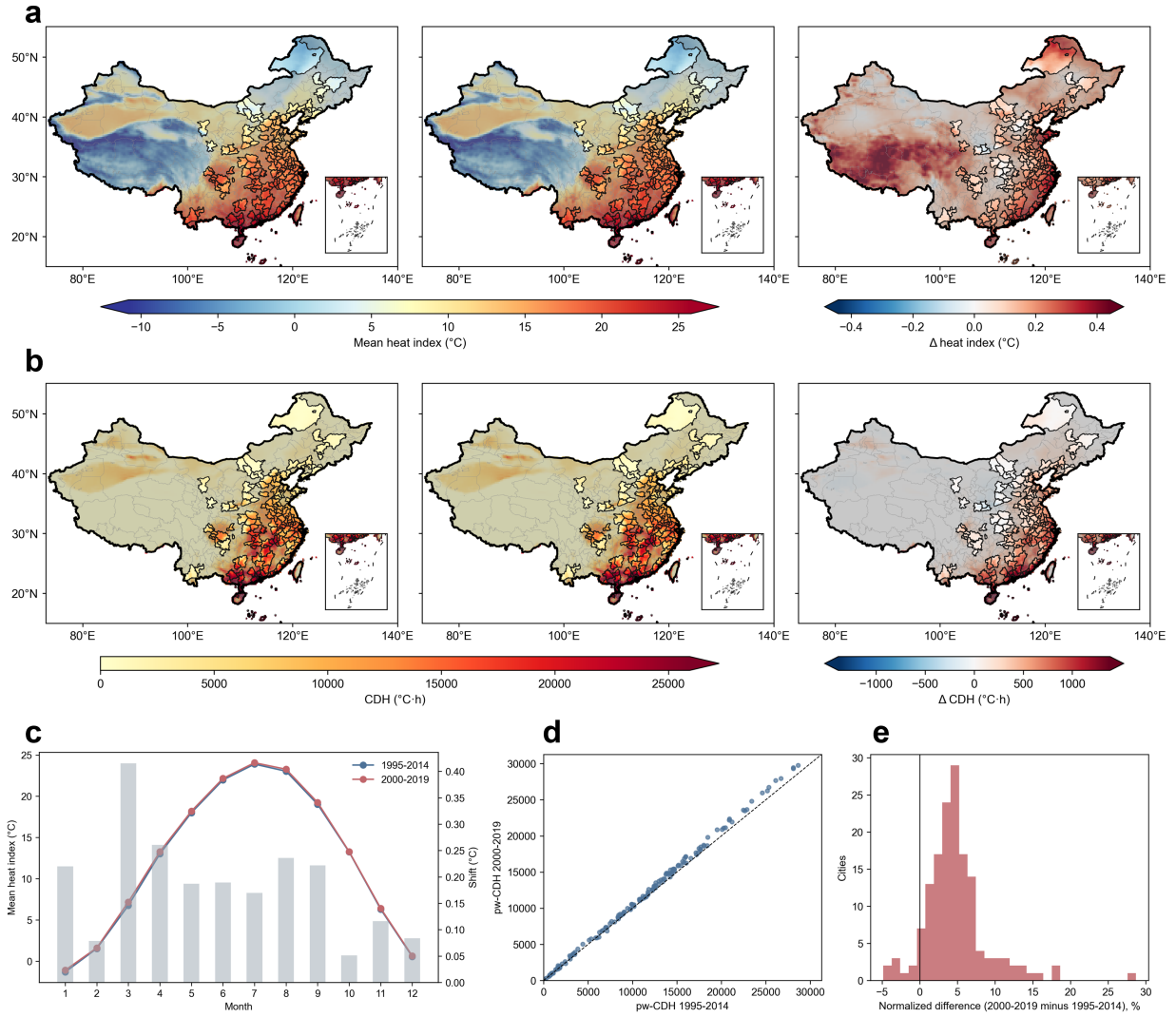


Fig. S9 | ERA5 climate validation across the two reference windows (1995–2014 and 2000–2019). **a**, Mean heat index for each window and their difference (°C). Sample cities are outlined in black and nonsample cities are shaded grey. **b**, Annual heat-index-based cooling degree-hours (above the cooling threshold) for each window and their difference. **c**, Monthly heat-index climatology averaged over China, with the per-month shift on the right axis. **d**, Population-weighted city-level CDH in each window. **e**, Normalized per-city difference between the windows.

Table S1 | Alternative cooling and heating thresholds*Panel A. CDH threshold varying from 24 to 28 °C, HDH threshold fixed at 11 °C*

	24	25	26	27	28
pw-CDH	0.0702*** (0.0172)	0.0732*** (0.0178)	0.0765*** (0.0187)	0.0800*** (0.0198)	0.0839*** (0.0211)
pw-HDH	0.0533 (0.0323)	0.0529 (0.0323)	0.0526 (0.0323)	0.0522 (0.0324)	0.0520 (0.0324)
Constant	7.3230*** (1.5144)	7.3380*** (1.5160)	7.3519*** (1.5177)	7.3646*** (1.5191)	7.3757*** (1.5199)
Observations	1860	1860	1860	1860	1860
Cities	151	151	151	151	151
Within R^2	0.105	0.105	0.105	0.104	0.104
City-segment fixed effects	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes

Panel B. HDH threshold varying from 9 to 13 °C, CDH threshold fixed at 26 °C

	9	10	11	12	13
pw-CDH	0.0762*** (0.0188)	0.0763*** (0.0188)	0.0765*** (0.0187)	0.0768*** (0.0187)	0.0771*** (0.0187)
pw-HDH	0.0531 (0.0339)	0.0527 (0.0331)	0.0526 (0.0323)	0.0526* (0.0316)	0.0529* (0.0310)
Constant	7.3803*** (1.5181)	7.3664*** (1.5179)	7.3519*** (1.5177)	7.3370*** (1.5173)	7.3215*** (1.5168)
Observations	1860	1860	1860	1860	1860
Cities	151	151	151	151	151
Within R^2	0.104	0.104	0.105	0.105	0.105
City-segment fixed effects	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes

Notes: The cooling coefficient is positive and significant at the 1% level for every cooling threshold from 24 to 28 °C, rising with the threshold because fewer degree-hours remain and each carries more weight. The heating coefficient remains small and insignificant for every threshold from 9 to 13 °C. Standard errors clustered at the city level are reported in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Table S2 | Urban status and household size as moderators of the climate response

	(1) Urban only	(2) HH size only	(3) Both, jointly
pw-CDH	0.1360*** (0.0340)	0.1051*** (0.0222)	0.1161*** (0.0330)
pw-CDH $\times$ Urban	-0.0216 (0.0384)		-0.0158 (0.0365)
pw-CDH $\times$ HH size		0.2884*** (0.1052)	0.2848*** (0.1041)
pw-HDH	0.0696 (0.0687)	0.0096 (0.0452)	0.0673 (0.0641)
pw-HDH $\times$ Urban	-0.0967* (0.0562)		-0.1021* (0.0582)
pw-HDH $\times$ HH size		0.0786 (0.0672)	0.0632 (0.0732)
Constant	9.2777*** (1.6199)	9.1451*** (1.7637)	9.2868*** (1.6150)
Observations	1071	1071	1071
Cities	70	70	70
Within R^2	0.097	0.107	0.112
City $\times$ Sector segment fixed effects	Yes	Yes	Yes
Sector $\times$ Year fixed effects	Yes	Yes	Yes

Notes: The dependent variable is the natural log of sector residential electricity on the stacked urban and rural panel, restricted to the subsample where household size is reported. Column 1 is the fully interacted urban model of Table 2, column 1 on this subsample. Column 2 interacts the cooling and heating terms with mean-centered log household size only. Column 3 enters both moderators jointly. City-by-sector and sector-by-year fixed effects are included. The urban interaction more than halves relative to the full sample and becomes insignificant. When both moderators enter jointly, the household-size interaction is virtually unchanged while the urban interaction shrinks further, suggesting that household structure is the more fundamental driver. Standard errors clustered at the city level are reported in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Table S3 | Cooling and heating response by tercile of GDPPC

	(1) Baseline	(2) GDPPC terciles
pw-CDH	0.0765*** (0.0187)	
pw-CDH $\times$ Low GDPPC		0.0922*** (0.0307)
pw-CDH $\times$ Middle GDPPC		0.0660*** (0.0218)
pw-CDH $\times$ High GDPPC		0.0652*** (0.0199)
pw-HDH	0.0526 (0.0323)	
pw-HDH $\times$ Low GDPPC		0.0559* (0.0310)
pw-HDH $\times$ Middle GDPPC		0.0413 (0.0317)
pw-HDH $\times$ High GDPPC		0.0187 (0.0332)
Constant	7.3519*** (1.5177)	7.7292*** (1.4668)
Observations	1860	1860
Cities	151	151
Within R^2	0.105	0.123
City-segment fixed effects	Yes	Yes
Year fixed effects	Yes	Yes

Notes: Column 1 reproduces the Table 1 baseline. Column 2 interacts pw-CDH and pw-HDH with tercile indicators of log real GDPPC, so that each row gives the slope for that tercile. Because the terciles are time-varying, the indicators enter as controls alongside GDPPC, population, and precipitation (not shown). Two-way fixed effects (city-segment, year). The cooling coefficient declines from 0.092 in the poorest third to 0.065 in the richest, but the pairwise differences are not statistically distinguishable, consistent with the null on the continuous interaction in Table 3. Standard errors clustered at the city level are reported in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Table S4 | Data sources for the observed panel and the projections. The observed period is 2000–2020 for socio-economic variables and covers the same years for climate inputs. The historical baseline is 1995–2014 for climate and 2000–2019 for GDP and population, set by data availability. Future periods under four SSP scenarios are 2040–2059 (mid-future) and 2080–2099 (far future).

<i>Observed data, 2000–2020</i>			
Variable	Source	Spatial / temporal resolution	
Residential electricity (total, urban, rural), GDP and GDP index, CPI, urban and rural per capita disposable income, total and urban permanent population, urban and rural average household size, urban and rural air-conditioner ownership per 100 households	City statistical yearbooks	City-level, yearly	
Temperature, relative humidity, precipitation	CMFDv2 (He et al., 2025)	0.1°, 3-hourly interpolated to hourly	
Population weights	WorldPop (WorldPop, 2020)	1 km, yearly	
<i>Projections of heat index</i>			
Driving model	RCM	Resolution	Scenarios
UKESM1-0-LL (Coupled Model Intercomparison Project Phase 6, CMIP6)	CCLM	0.22°	Historical, SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP5-8.5
	HadGEM3-RA (HG3RA)	0.22°	
	RegCM4 (RegCM)	25 km	
	WRF	25 km	
<i>Projections of socio-economic conditions</i>			
Variable	Reference	Resolution	Scenarios
GDP	Wang and Sun (2022)	1 km	Historical, SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP5-8.5
Population	WorldPop (2020)	1 km	Historical
	Wang et al. (2022)	1 km	SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP5-8.5

Table S5 | Reporting-break sensitivity of the primary specification

	(1) Primary (50%)	(2) No breaks	(3) Break 35%	(4) Break 100%
pw-CDH	0.0765*** (0.0187)	0.0667*** (0.0203)	0.0723*** (0.0174)	0.0693*** (0.0201)
pw-HDH	0.0526 (0.0323)	0.0416 (0.0315)	0.0639** (0.0258)	0.0433 (0.0311)
Population	0.1908 (0.1389)	0.2285 (0.1421)	0.1730 (0.1439)	0.2441* (0.1429)
GDPPC	0.3503*** (0.0814)	0.3380*** (0.0822)	0.3709*** (0.0850)	0.3488*** (0.0820)
Precipitation	-0.0113 (0.0110)	-0.0192 (0.0129)	-0.0098 (0.0106)	-0.0183 (0.0126)
Constant	7.3519*** (1.5177)	7.2886*** (1.4650)	7.2292*** (1.5882)	7.0760*** (1.4702)
Observations	1860	1866	1858	1863
Cities	151	151	151	151
Within R^2	0.105	0.072	0.125	0.091
City-segment fixed effects	Yes	No	Yes	Yes
City fixed effects	No	Yes	No	No
Year fixed effects	Yes	Yes	Yes	Yes

Notes: Column 1 reproduces Table 1, column 4, which splits a city's series wherever reported residential electricity moves by more than 50% between consecutive years and absorbs one fixed effect per segment. Column 2 replaces city-segment fixed effects with a single city fixed effect. Columns 3 and 4 move the break threshold to 35% and 100%. The cooling coefficient is stable across all four treatments. Observations differ slightly across columns because a single-year segment leaves the sample as a singleton. Standard errors clustered at the city level are reported in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Table S6 | Descriptive statistics. Panel A covers the city-level estimation sample (1,860 city-year observations from 151 cities). Panels B and C cover the urban and rural rows of the stacked sector sample. All variables are shown in their original units, before any log transformation. Household size and air-conditioner ownership are observed on subsets, so their N is smaller. City air-conditioner ownership is the urban-share-weighted mean of the urban and rural values.

Variable	Description	N	Mean	SD	Min	Max
<i>Panel A. City level</i>						
Residential electricity	Total residential electricity, in 10,000 kWh	1,860	339,415.49	355,142.20	8,200.00	2,797,925.00
pw-CDH	Population-weighted CDH, in 10,000 degree-hours	1,860	1.29	0.73	0.00	4.10
pw-HDH	Population-weighted HDH, in 10,000 degree-hours	1,860	2.04	1.78	0.00	12.65
GDPPC	Real GDP per capita (2000 prices), in yuan	1,860	34,502.94	20,192.38	2,689.24	105,104.61
Population	Permanent population, in 10,000 persons	1,860	571.54	413.07	81.90	3,208.93
Precipitation	Population-weighted annual precipitation, in mm/year	1,860	1,243.17	554.13	251.18	3,039.84
Urbanization	Urban share of population, in percent	1,463	58.24	15.09	11.24	94.67
AC ownership	Air conditioners owned per 100 households	637	126.90	61.68	0.50	283.56
<i>Panel B. Urban sector</i>						
Residential electricity	Sector residential electricity, in 10,000 kWh	1,114	191,824.28	240,098.91	9,562.00	2,306,966.00
pw-CDH	Sector population-weighted CDH, in 10,000 degree-hours	1,114	1.36	0.85	0.01	4.88
pw-HDH	Sector population-weighted HDH, in 10,000 degree-hours	1,114	2.02	1.66	0.00	9.06
Income	Real per capita disposable income (2000 prices), in yuan	1,114	21,939.92	7,648.08	4,226.86	51,682.00
Population	Sector permanent population, in 10,000 persons	1,114	332.97	300.12	34.07	1,916.40
Precipitation	Sector population-weighted annual precipitation, in mm/year	1,114	1,191.86	568.59	190.90	3,627.79
Household size	Average household size, in persons	562	3.04	0.32	2.50	4.50
AC ownership	Air conditioners owned per 100 households	622	143.77	67.66	0.02	287.50
<i>Panel C. Rural sector</i>						
Residential electricity	Sector residential electricity, in 10,000 kWh	1,059	144,597.34	126,632.29	3,967.00	831,881.00
pw-CDH	Sector population-weighted CDH, in 10,000 degree-hours	1,059	1.31	0.79	0.00	4.44
pw-HDH	Sector population-weighted HDH, in 10,000 degree-hours	1,059	2.07	1.69	0.00	9.22
Income	Real per capita disposable income (2000 prices), in yuan	1,059	9,887.91	4,346.48	1,934.57	26,281.95
Population	Sector permanent population, in 10,000 persons	1,059	211.35	127.17	19.27	688.24
Precipitation	Sector population-weighted annual precipitation, in mm/year	1,059	1,238.37	567.33	288.02	2,823.28
Household size	Average household size, in persons	519	3.41	0.48	2.13	4.74
AC ownership	Air conditioners owned per 100 households	616	79.92	58.88	0.00	279.10

Table S7 | Climate measure: heat-index-based vs. temperature-based CDH/HDH

	(1) Heat index	(2) Temperature
pw-CDH	0.0765*** (0.0187)	
pw-HDH	0.0526 (0.0323)	
pw-CDH (temperature-based)		0.2110*** (0.0341)
pw-HDH (temperature-based)		0.0630** (0.0313)
GDPPC	0.3503*** (0.0814)	0.3393*** (0.0805)
Population	0.1908 (0.1389)	0.1868 (0.1368)
Precipitation	-0.0113 (0.0110)	0.0065 (0.0114)
Constant	7.3519*** (1.5177)	7.4282*** (1.4942)
Observations	1860	1860
Cities	151	151
Within R^2	0.105	0.109
City-segment fixed effects	Yes	Yes
Year fixed effects	Yes	Yes

Notes: The sample and controls are held fixed across columns. The heat-index-based measure, which embeds humidity, is the primary specification. The temperature-based measure yields a larger coefficient because dry-bulb temperature produces fewer degree-hours per year and each carries more weight. Standard errors clustered at the city level are reported in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Table S8 | Projection parameters. The cooling coefficient is a semi-elasticity per 10,000 pw-CDH from the primary specification. Socioeconomic parameters use modeling ranges informed by fitted specifications and imposed assumptions.

Driver	Parameter	Value	Source specification
<i>Climate, per 10,000 pw-CDH</i>			
pw-CDH	central	0.0765	Table 1 column 4, city-segment and year fixed effects (SE 0.0187)
pw-CDH	95% interval	0.0398 to 0.1131	central $\pm$ 1.96 standard errors
<i>Socioeconomic, elasticities</i>			
ln GDPPC	lower	0.35	Table 1 column 4 GDPPC coefficient (0.3503)
ln GDPPC	central	0.70	assumed value between the bounds, not an estimate
ln GDPPC	upper	0.98	same regression with city-segment effects only and no year effects (0.9772)
ln population	lower	0.808	same city-segment-effects-only specification ^a
ln population	central	0.90	assumed value between the bounds, not an estimate
ln population	upper	1.00	proportional scaling of demand with residents, imposed

^a Both socioeconomic bounds come from the estimating equation with city-segment effects alone. Using a plain city effect instead, which leaves reporting breaks in, gives 0.879.

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