Supplementary Material

Supplementary information for The effectiveness of heat prevention plans to reduce heat-related mortality in Europe

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S1 Data description

Table S1 Description of the mortality data used in the study

Country	Location	Period	Mortality data	Temperature data
Czechia	3 cities (Prague, Brno, Ostrava)	1994–2019	All causes provided by the Czech Statistical Office and the Institute of Health Information and Statistics.	Mean daily temperature data provided by the Czech Hydrometeorological Institute (CHMI)
Finland	1 metropolitan area (Helsinki)	1994–2014	All causes provided by Statistics Finland	Mean daily temperature obtained from the Finnish Meteorological Institute
France	20 cities (Bordeaux, Clermont-Ferrand, Dijon, Grenoble, Le, Havre, Lens-Douai, Lille, Lyon, Marseille, Montpellier, Nancy, Nantes, Nice, Orleans, Paris, Rennes, Rouen, Strasbourg, Toulouse, Tours)	2000–2017	All causes provided by French National Institute of Health and Medical Research (CepiDC).	Mean daily temperature from obtained from Meteo France
Germany	14 cities (Berlin, Bremen, Dortmund, Dresden, Duisburg, Düsseldorf, Frankfurt, Hamburg, Hannover, Köln, Leipzig, München, Nüremberg, Stuttgart)	1993–2019	All causes provided by Research Data Centres of the Federation and the Federal States of Germany (Forschungsdatenzentrum der Statistischen Ämter des Bundes und der Länder).	Mean daily temperature from obtained from German Weather Service (DWD)
Italy	9 cities (Bari, Bologna, Cagliari, Florence, Genoa, Milan, Palermo, Rome, Viterbo)	1990–2015	All causes provided by the obtained from local mortality registries and from the rapid mortality surveillance system.	Mean daily temperature from obtained from Meteorological Service of the Italian Air Force
The Netherlands	5 cities (Amsterdam, Den Haag, Eindhoven, Rotterdam, Utrecht)	1995–2016	All causes data obtained from of Statistics Netherlands (CBS)	Mean daily temperature data were obtained from the Royal Dutch Meteorological Institute (KNMI)
Poland	5 cities (Krakow, Lodz, Poznan, Warsaw, Wroclaw)	1991–2019	All cause mortality data was obtained from National Institute of Public Health.	Mean daily temperature data were obtained from institute of Meteorology and Water Management.

Portugal	5 districts (Beja, Coimbra, Faro, Lisboa, Porto)	1990–2018	All cause mortality data was extracted from the national death registries (Statistics Portugal)	Mean daily temperature data were extracted from NOAA website
Romania	8 cities (Brasov, Bucharest, Cluj-Napoca, Constanta, Craiova, Galati, Iasi, Timisoara)	1994–2016	All causes - Romanian National Institute of Statistics	Mean daily temperature - National Meteorological Administration of Romania (NMARO, accessed from https://www.ecad.eu/)
Serbia	1 city (Belgrade)	1995–2019	All causes - Statistical Office of the Republic of Serbia	Meteorological data - WMO-NOAA Surface Data Hourly Global (DS3505)
Spain	11 cities (A Coruna, Barcelona, Bilbao, Cordoba, Madrid, Malaga, Murcia, Sevilla, Toledo, Valencia, Zaragoza)	1991–2014	Non–external causes (ICD–9: 0–799; ICD–10: A00–R99) from the Spain National Institute of Statistics.	Mean daily temperature data were obtained from Spain National Meteorology Agency
Sweden	3 cities (Gothenburg, Malmo, Stockholm)	1990–2016	All cause mortality data was obtained from the Swedish Cause of Death Register at the Swedish National Board of Health and Welfare	Mean daily temperature data were obtained from Environment and Health Administration
Switzerland	8 cities (Basel, Bern, Geneve, Lausanne, Lugano, Luzern, St. Gallen, Zurich)	1995–2013	Non–external causes only other than accidents (ICD–10codes A00–R99, V01–V99, W00–X59) provided from Federal Office of Statistics (Switzerland).	Mean daily temperature data were obtained from IDAweb database (Federal Office of Meteorology and Climatology, MeteoSwiss)
England and Wales (UK)	9 cities (Birmingham, Cardiff, Liverpool, London, Manchester, Newcastle-under-Lyme, Newcastle upon Tyne, Portsmouth, Southampton)	1990–2019	All causes provided by the Office of National Statistics.	Mean daily temperature data were obtained from Met Office.

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S2 HPP score calculation

The final score of each HPP is a sum of actions implemented in the plan and weighted by its importance based on the expert elicitation outcome (Table S2). Due to difficulties with collecting relevant information, we excluded core elements 7 "Long-term urban planning" and 8 "Real-time surveillance and evaluation" from the assessment.

Although HPPs are usually implemented on a regional level, we were not able to collect consistent information on regional HPPs across Europe. Therefore, we considered the year of implementation and HPP score of the national HPP being universal for the whole country. Similarly, since we were not able to track updates of all HPPs consistently, the HPP score in the post implementation period was based on the level of HPPs at the time of the analysis (i.e., we did not consider possible updates since the year of implementation).

Table S2 WHO core elements and maximum HPP score for each element reached among the examined HPPs. The potential maximum points in the brackets indicate the maximum possible score that could have been achieved for each core element.

CORE ELEMENTS	MAXIMUM (POTENTIAL) WEIGHTED POINTS[a]
1) Agreement on a lead body	3 (7)
2) Accurate and timely alert systems	11 (15)
3) Health information plan	8 (10)
4) Reduction in indoor heat exposure	3 (43)
5) Particular care for vulnerable groups	6 (7)
6) Preparedness of the health/social care system	6 (9)
7) Long-term urban planning	–[b]
8) Real-time surveillance and evaluation	–[b]
Total HPP score	31 (48)

[a] Based on results of the Expert Elicitation Workshop: https://docs.google.com/forms/d/1kRRQf2Jc4emIi2XYXBS9tmGyD2E0Mkv4K6ZFcu3zEw8/viewanalytics

[b] Not included due to unavailable or inconsistent data in analysed documents.

Table S3 Definition of HPP classes

HPP class	Definition
HPP = ?	**No data**
HPP class 0	**No/basic weather forecast before HPP implementation**
HPP class 1	**HPP score ≤ 10**
HPP class 2	**10 > HPP score ≤ 20**
HPP class 3	**HPP score > 20**

S3 Sensitivity analysis

Six versions of the second-stage meta-regression model were compared to test the sensitivity of the effect of HPP implementation on a) underlying trends in heat-related mortality risks, b) regional differences in the HPP effect, and c) the type of HPP implemented in individual countries (HPP class). The basic model was defined as follows:

$$\boldsymbol{\theta_{it}} = \boldsymbol{\beta X_{it}} + \boldsymbol{\gamma_{it}} + \boldsymbol{\delta_i} + \boldsymbol{\epsilon_{it}}$$

where $\boldsymbol{\theta_{it}}$represents reduced coefficients from Stage 1 for location ***i*** and subperiod $\boldsymbol{t}$, $\boldsymbol{X_{it}}$ is a set of the fixed-effect predictors of the meta-analytical model with the associated coefficients $\boldsymbol{\beta}$, $\boldsymbol{\gamma_{it}}$ and $\boldsymbol{\delta_i}$ represent subperiod within city random intercepts to additionally control for city-and subperiod specific differences in vulnerability, while $\boldsymbol{\epsilon_{it}}$ is the residual variability.

Different combinations of the fixed-effect predictors ($\boldsymbol{X_{it}}$) were defined as follows:

Model 0: $\boldsymbol{X_{it}} = \boldsymbol{HPP_{it}}$,

Model 1: $\boldsymbol{X_{it}} = \boldsymbol{HPP_{it}} + \boldsymbol{Region_i}$,

Model 2: $\boldsymbol{X_{it}} = \boldsymbol{HPP_{it}} + \boldsymbol{Region_i} + \boldsymbol{Time_t}$,

Model 3: $\boldsymbol{X_{it}} = \boldsymbol{HPP_{it}} + \boldsymbol{Region_i} + \boldsymbol{Time_t} + \boldsymbol{Region_i} * \boldsymbol{Time_t}$,

Model 4: $\boldsymbol{X_{it}} = \boldsymbol{HPP_{it}} * \boldsymbol{Region_i} + \boldsymbol{Region_i} + \boldsymbol{Time_t} + \boldsymbol{Region_i} * \boldsymbol{Time_t}$,

Model 5: $\boldsymbol{X_{it}} = \boldsymbol{HPP_{it}} * \boldsymbol{HPPclass_i} + \boldsymbol{Region_i} + \boldsymbol{Time_t} + \boldsymbol{Region_i} * \boldsymbol{Time_t}$,

where $\boldsymbol{HPP_{it}}$ is an indicator for the presence of HPP in each location ***i*** and subperiod $\boldsymbol{t}$, defined as 0 if its implementation occurred earlier or in the first year of the subperiod, in which the HPP started, and 1 otherwise, $\boldsymbol{Region}$ defines the position of each location ***i*** in one of the four geographical regions (Figure 1), $\boldsymbol{Time}$ represents a linear time trend specified as a continuous variable using the mid-year of each subperiod $\boldsymbol{t}$ (Figure S1), "*****" operator defines the interaction term between two predictors, and $\boldsymbol{HPPclass_i}$ defines the HPP class in each location ***i*** (Figure S1 and S3). Parameters of the models tested and their comparison via a likelihood ratio test (LRT) is present in Table S4.

Table S4 Comparison of models used in the sensitivity analysis. Model parameters include log-likelihood (*Log Lik*), Cochran *Q* test values, Moran's I^2 criterion and Akaike Information Criterion (*AIC*). Likelihood ratio test (LRT) was used to compare the individual models. Model 3 (bold) is the model used in the main manuscript.

Model	**Model parameters**					**LRT**		
	df	*Log Lik*	*AIC*	I^2	*Q*	*Models compared*	*Chisq*	*Pr(>Chisq)*
Model 0	16	−1759.11	3550.2	54.3	6507			
Model 1	*28*	*−1706.74*	*3469.5*	*44.3*	*5323*	*Model 1 vs. Model 0*	*104.75*	*< 0.001*
Model 2	32	−1704.94	3473.9	44.1	5292	Model 2 vs. Model 1	3.60	0.460
Model 3	***44***	***−1686.84***	***3461.7***	***43.7***	***5238***	***Model 3 vs. Model 2***	***36.19***	***< 0.001***
Model 4	56	−1680.83	3473.7	43.3	5175	Model 4 vs. Model 3	12.02	0.440
Model 5	52	−1681.23	3466.5	43.3	5188	Model 5 vs. Model 3	11.24	0.190

Table S5 Pooled relative risk of temperature-related mortality at the 99th percentile (RR_{99}) of May–September mean daily temperature distribution, as estimated by Models 3 and 4 for subperiod 2014–2016 (after HPP implementation) in each Region, without (counterfactual) vs. with (factual) the effect of HPP.

Region	**Model 3**		**Model 4**	
	counterfactual (RR_{99})	*factual (RR_{99})*	*counterfactual (RR_{99})*	*factual (RR_{99})*
Northern Europe	1.29 (1.16; 1.42)	1.16 (1.06; 1.28)	1.32 (1.18; 1.48)	1.15 (1.04; 1.27)
Eastern Europe	1.43 (1.31; 1.56)	1.29 (1.19; 1.40)	1.37 (1.23; 1.53)	1.29 (1.19; 1.40)
Western Europe	1.36 (1.28; 1.45)	1.23 (1.16; 1.29)	1.34 (1.24; 1.43)	1.22 (1.16; 1.29)
Southern Europe	1.54 (1.39; 1.69)	1.38 (1.26; 1.51)	1.61 (1.41; 1.83)	1.39 (1.27; 1.52)
Mean	1.41 (1.35; 1.46)	1.27 (1.22; 1.31)	1.41 (1.34; 1.48)	1.26 (1.21; 1.31)

Table S6 Pooled relative risk of temperature-related mortality at the 99th percentile (RR_{99}) of May–September mean daily temperature distribution, as estimated by Model 5 for subperiod 2014–2016 (after HPP implementation) in each Region, without (counterfactual) vs. with (factual) the effect of HPP. The factual effect is stratified by the HPP class, i.e., the level of development of HPPs (see Tables S2 and S3).

Region	**counterfactual (RR_{99})**	**factual - HPP class 1 (RR_{99})**	**factual - HPP class 2 (RR_{99})**	**factual - HPP class 3 (RR_{99})**
Northern Europe	1.29 (1.17; 1.43)	1.16 (1.03; 1.31)	1.18 (1.05; 1.33)	1.16 (1.05; 1.28)
Eastern Europe	1.29 (1.17; 1.43)	1.16 (1.03; 1.31)	1.18 (1.05; 1.33)	1.16 (1.05; 1.28)
Western Europe	1.41 (1.28; 1.56)	1.26 (1.14; 1.39)	1.30 (1.19; 1.42)	1.27 (1.15; 1.41)
Southern Europe	1.36 (1.27; 1.44)	1.21 (1.10; 1.33)	1.26 (1.17; 1.36)	1.22 (1.15; 1.29)
Mean	1.35 (1.32; 1.39)	1.20 (1.17; 1.22)	1.23 (1.20; 1.26)	1.20 (1.18; 1.23)

COUNTRY	N LOCATIONS	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	
Finland	1 metropolitan area					0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	North
Sweden	3 cities	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	
UK	9 cities	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
Czechia	3 cities					0	0	0	0	0	0	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	East
Romania	8 cities					0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
Poland	5 cities		0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Serbia	1 city						0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2	2	2	2	2	2	2	2	2	2	
France	20 cities											0	0	0	0	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	West
Germany	14 cities				0	0	0	0	0	0	0	0	0	0	0	0	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
Netherlands	5 cities						0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2	2	2	2	2	2	2	2	2	2	
Switzerland	8 cities						0	0	0	0	0	0	0	0	0	0	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
Italy	10 cities	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	South
Portugal	5 districts	0	0	0	0	0	0	0	0	0	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
Spain	11 cities	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	

Figure S1 Temporal structure of the data used in the study. Coloured years indicate mortality data available for the analysis. Numbers indicate the HPP class (1–3; according to Table S2). 0 = no HPP. Border lines delimitate the three-year subperiods used in the longitudinal study design.

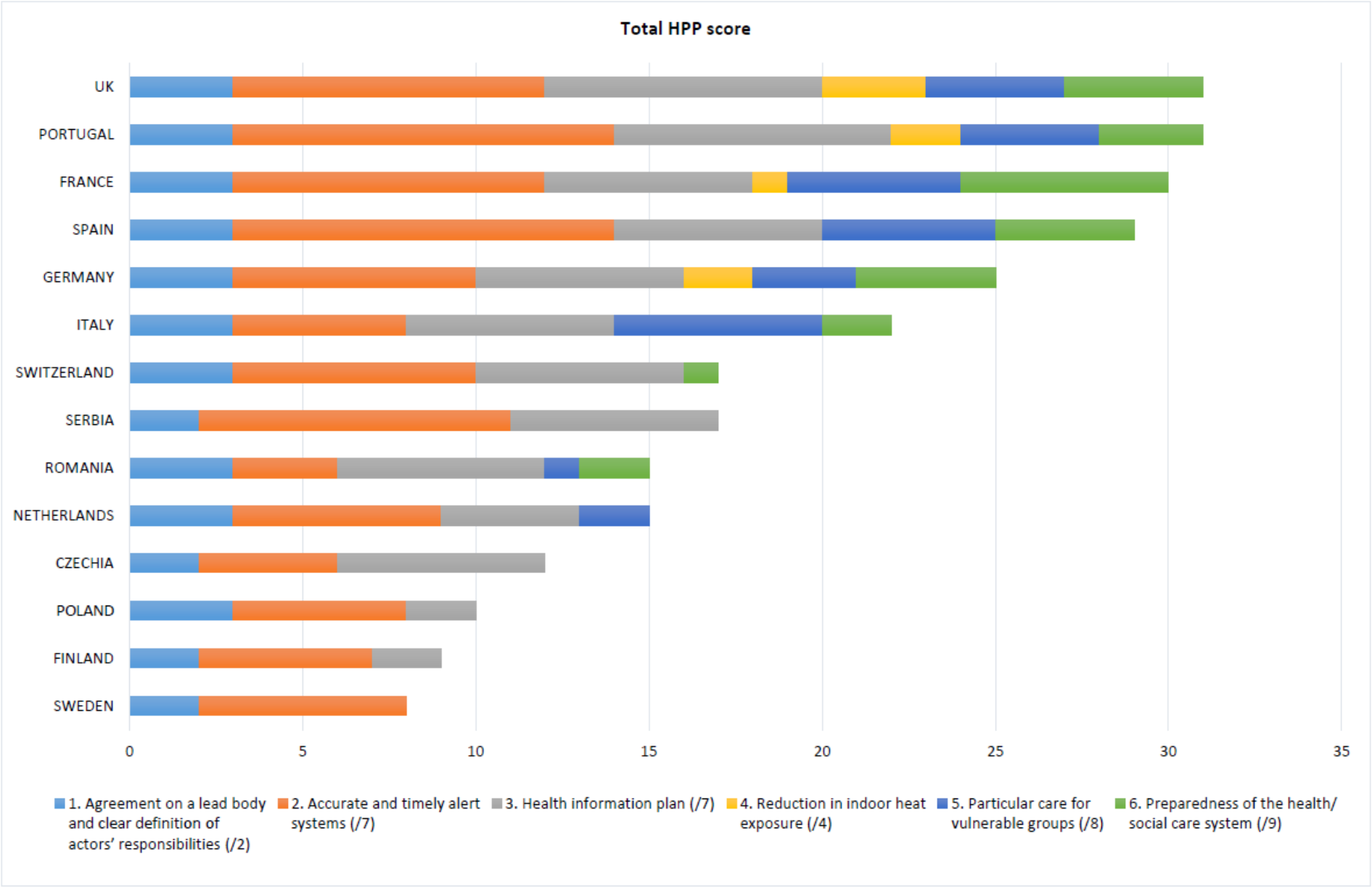


Figure S2 HPP score in the countries based on the WHO core elements analysed in the study. Maximum potential score for each element is stated in parentheses. The score is based on the Expert Elicitation Workshop.

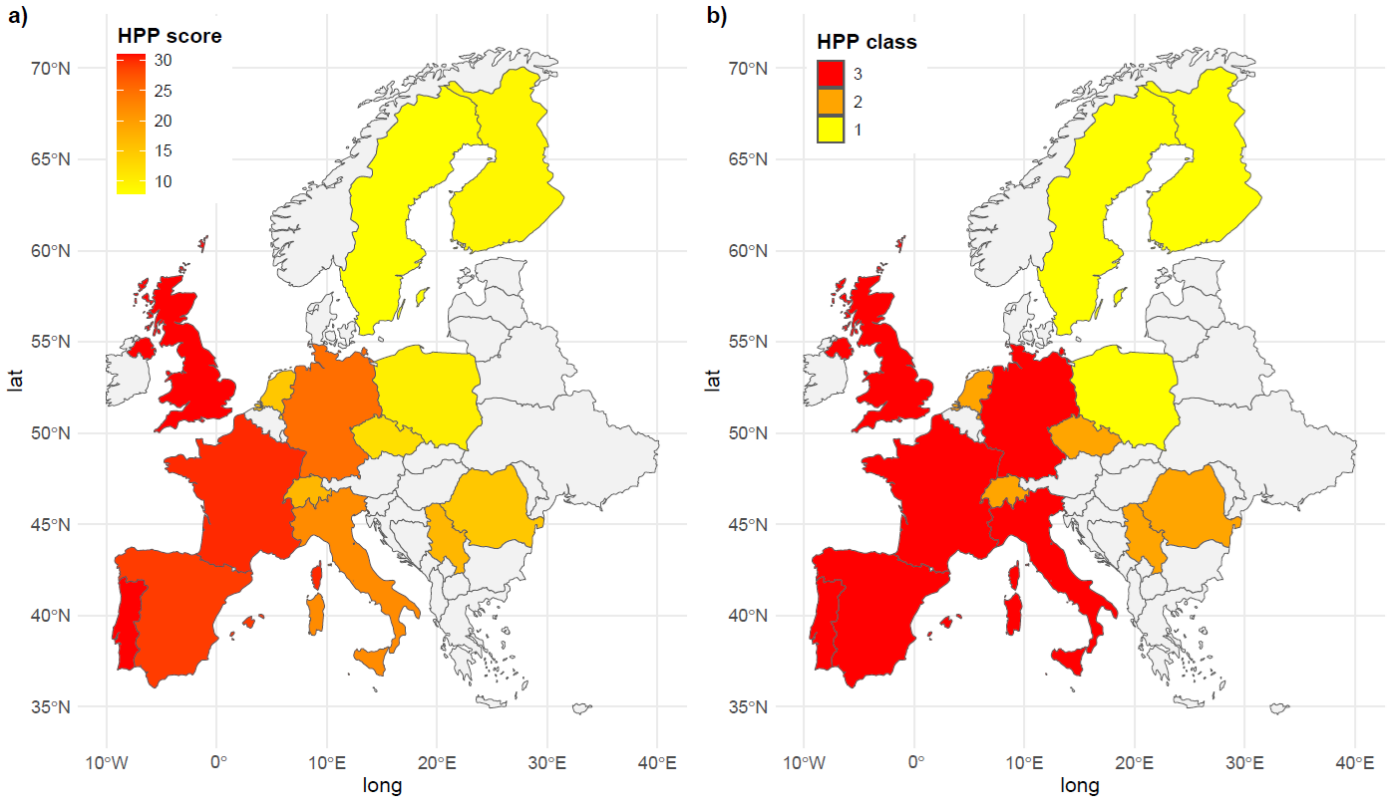
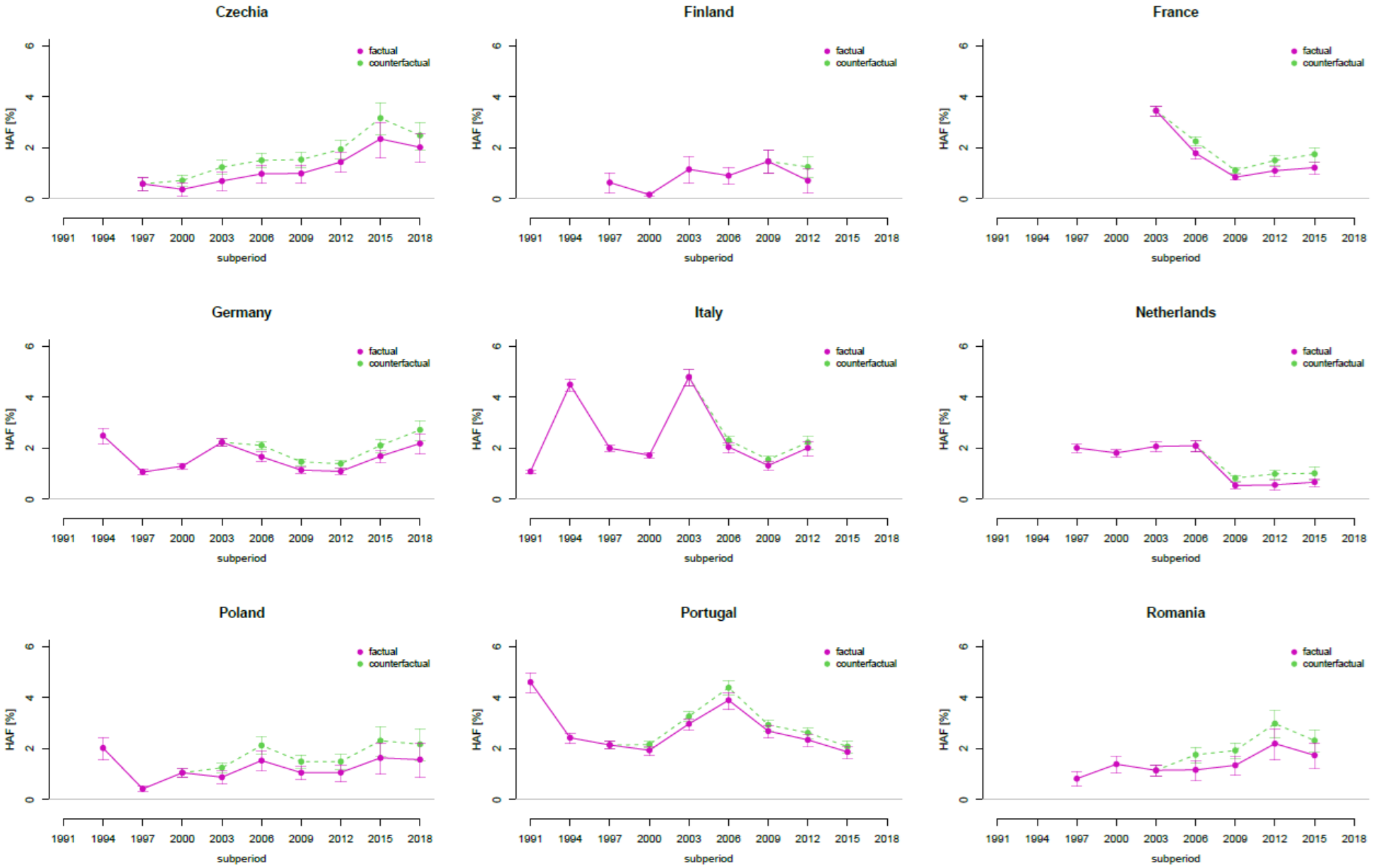


Figure S3 National HPP score (a) and HPP class (b) in the study regions after HPP implementation. Grey colour indicates that no relevant mortality or HPP data were available for the purpose of our study. Note: for simplification, only the latest information about individual HPP elements is considered in the final HPP score, i.e., we did not track possible upgrades since the year of implementation. Analogically, we consider one HPP score for each country, although the stage of implementation may differ in individual cities.


Czechia
Finland
France
Germany
Italy
Netherlands
Poland
Portugal
Romania
factual
counterfactual
HAF [%]
subperiod
0
2
4
6
1991
1994
1997
2000
2003
2006
2009
2012
2015
2018

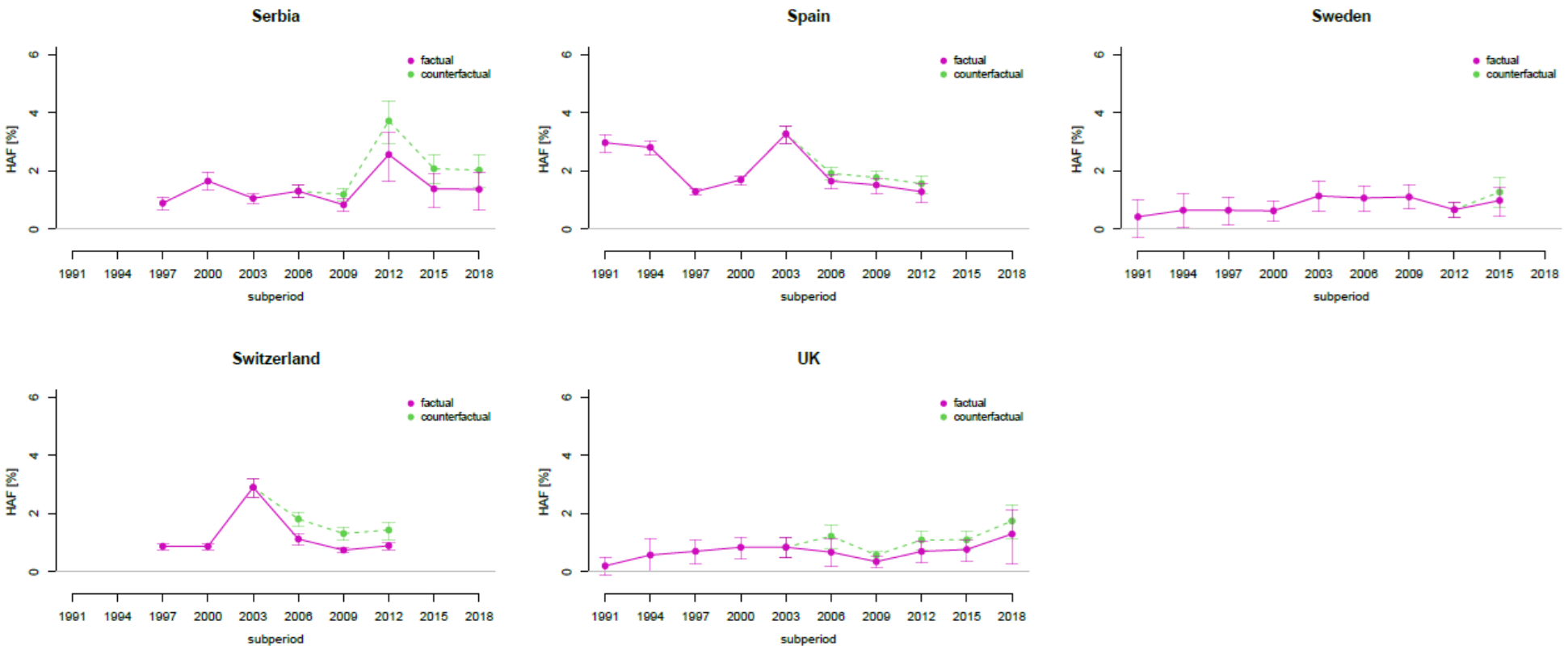


Figure S4 Temporal change in Heat-Attributable Fractions by subperiods in individual countries

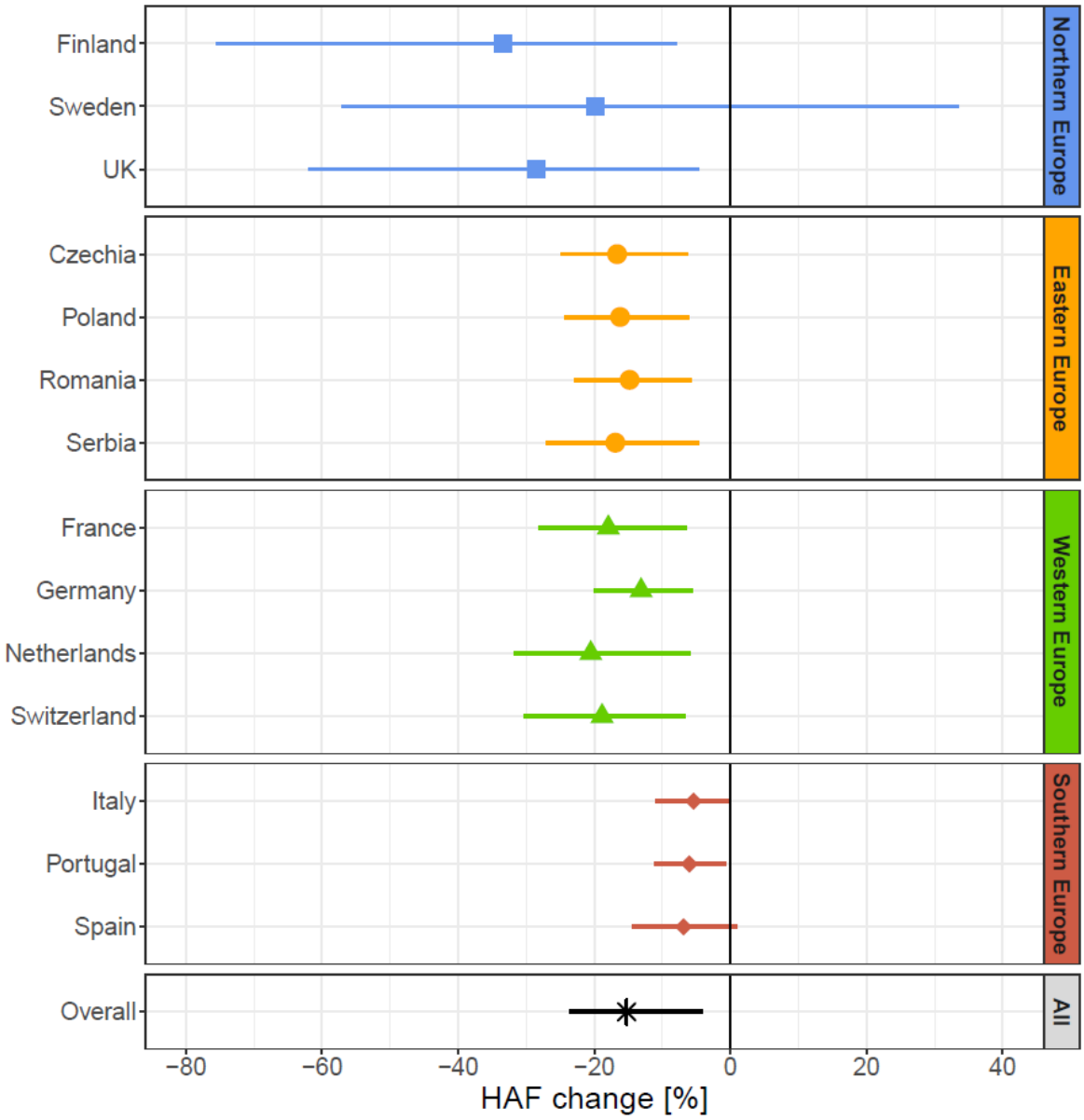


Figure S5 Changes in heat-attributable mortality fraction (quantified as a relative difference between the counterfactual and the factual scenarios) per country associated with HPP implementation, after exclusion of the summer of 2003 from the analysis. Error bars indicate 95% empirical confidence intervals calculated by Monte-Carlo simulations.