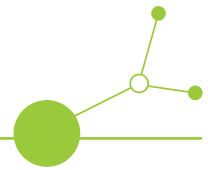


DELIVERABLE 1.4.1 LESSONS LEARNED FROM THE PAST DHF EVENTS (STRATEGY DOCUMENT)



Version 2

08 2025





DELIVERABLE 1.4.1 LESSONS LEARNED FROM THE PAST DHF EVENTS (STRATEGY DOCUMENT)

Lívia Labudová, Milan Onderka, Katarína Mikulová

Introduction

This strategy document summarizes the outcomes of discussions with public sector stakeholders and other relevant actors regarding past drought-heat-fire (DHF) events that had cross-border effects. It highlights differences in institutional and societal responses between countries, which have contributed to varying levels of DHF impact. Drawing on stakeholder consultations and legislative reviews conducted within Work Package 3 (WP3), this report evaluates each country's current response mechanisms to DHF events. The report is divided into three sections, each being targeted specifically on wildfires, droughts and heatwaves. Preliminary results of statistical analyses are presented for heat related cardiovascular mortalities, highlighting the differences between countries and regions.

A. Wildfires

The most advanced implementation of response mechanisms was observed in the area of wildfire management (Tab. 1). In four countries: Poland, Croatia, Slovenia, and Slovakia, more than half of the evaluated actions were assessed as fully implemented. In Slovakia, institutional responsibilities and communication channels among involved agencies are clearly defined both in legislation and in practice. Together with improved wildfire monitoring and forecasting, this may help explain the decreasing number of forest fires between 2000 and 2023 (Fig. 1), despite the occurrence of intensifying droughts in the second decade, which otherwise created favourable conditions for wildfires. A similarly well-established legislative framework exists in Croatia, where inter-institutional communication is generally strong. However, a persistent issue is the shortage of water for fire suppression in certain regions. Although firefighters have the legal authority to use available water sources, some bodies of water remain inaccessible. This may partially explain why the number of forest fires and burnt area in Croatia has not shown a significant decrease (Fig. 2), and why impacts of forest fires remain high. Similar situation with water shortage for firefighting was observed in Slovenia after longlasting drought period. By contrast, weaker implementation of response mechanisms was noted in Czechia, Austria, and Germany. In Germany, institutional responsibilities are fragmented across federal, state (Länder), and local levels, without binding coordination mechanisms for DHF events. This structural fragmentation results in inconsistent implementation and delayed responses, particularly in cross-sectoral or multi-Länder crises. Regarding heatwaves, Germany's institutional setup remains largely sectoral, with weak interlinkages. While data and knowledge generation is robust, their operational integration into emergency response remains limited. This may contribute to the observed slight increase in the annual number of wildfires in some German federal states in recent years (Fig. 3).

Concluding the lesson learnt from above described differences in institutional responses and communication among involved institutions in the Clim4Cast countries, well-established legislation framework defining clear institutional responsibility as well as effective communication flow are very important factors influencing the impact rates of wildfires. In addition to the institutional assessment, we conducted a preliminary analysis using delivered fire occurrence records aggregated by NUTS3



regions, combined with the Fire Weather Index. This allowed us to identify temporal patterns in wildfire activity and to detect potential structural breaks in the time series, which may be linked to changes in climate conditions, land management practices, or policy interventions. These exploratory results provide a basis for more detailed, quantitative modelling of wildfire risk in the regions.

Table 1. An evaluation, at which stage each of seven actions listed in the response phase of the conceptual scheme for proactive response to DHF events has already been implemented within wildfire management in each country of the Clim4Cast region (green - action fully implemented, yellow - action partly implemented, red - action not implemented).

Topic	Action	Croatia	Poland	Austria	Germany	Slovakia	Slovenia	Czechia
LEGISLATION	12. Implement legal frameworks for declaring DHF event emergencies (see action 1)	Yellow	Green	Green	Yellow	Green	Green	Yellow
	13. Implement protocol for effective DHF management (activities implemented in each stage of DHF as defined for example in DHF management plans) (see action 3)	Green	Green	Green	Yellow	Green	Green	Yellow
DATA AND KNOWLEDGE	14. Implement continuous DHF monitoring and integrate advanced DHF forecasting tools including generating and disseminating near-real time DHF status reports	Green	Green	Yellow	Yellow	Yellow	Yellow	Yellow
	15. Conduct comprehensive DHF impact assessments across key sectors (such as agriculture, water resources, public health, and infrastructure)	Yellow	Green	Yellow	Yellow	Yellow	Yellow	Yellow
COMMUNICATION	16. <i>“external”</i> Provide timely and accurate information to the public about the current and anticipated DHF situation and appropriate response measures that are based on measures identified in the DHF management plans	Green	Green	Yellow	Red	Yellow	Green	Yellow
	17. <i>“internal”</i> Follow defined communication flow and coordination mechanism (see actions 2 and 3), e.g., regular briefings, meetings with DHF committee, national authorities for coordinating actions	Green	Green	Yellow	Yellow	Green	Green	Green
	18. <i>“stakeholders engagement”</i> Engage with predefined set of stakeholders for support with implementation of measures	Green	Yellow	Yellow	Yellow	Green	Green	Green

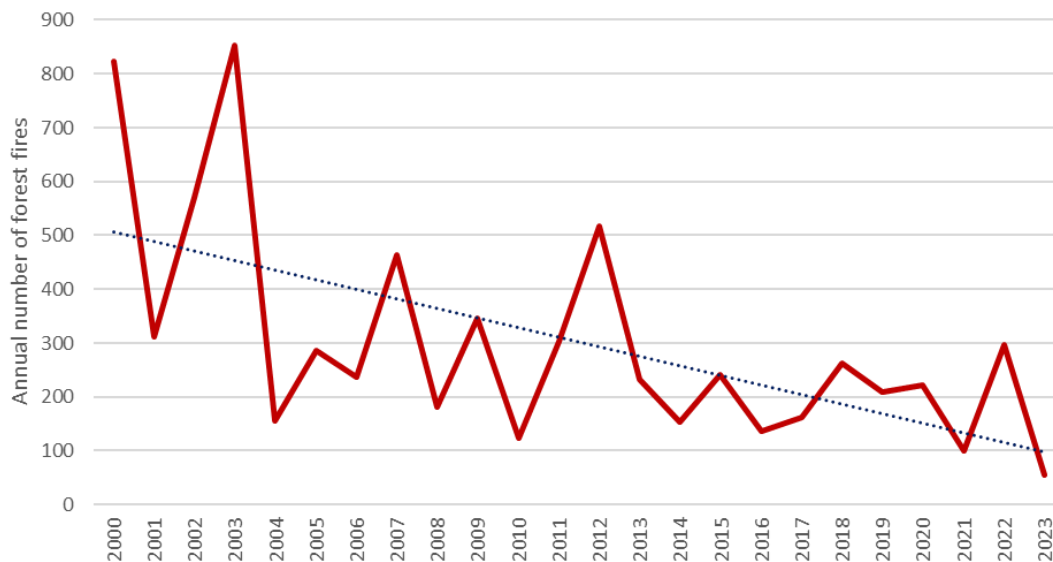


Figure 1. Annual number of forest fires in Slovakia with linear trend in the period 2000-2023 (Source: Forest Protection Service - associated partner of the Clim4Cast project).

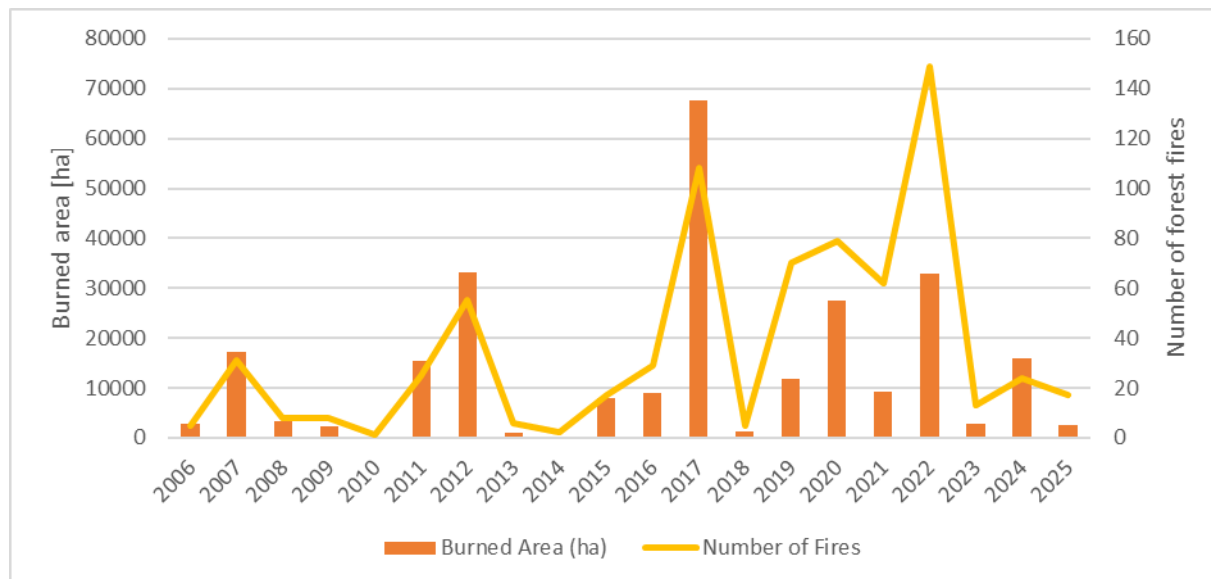


Figure 2. Annual number of forest fires and annual burned area in Croatia in the period 2006-2025 (Source: EFFIS).

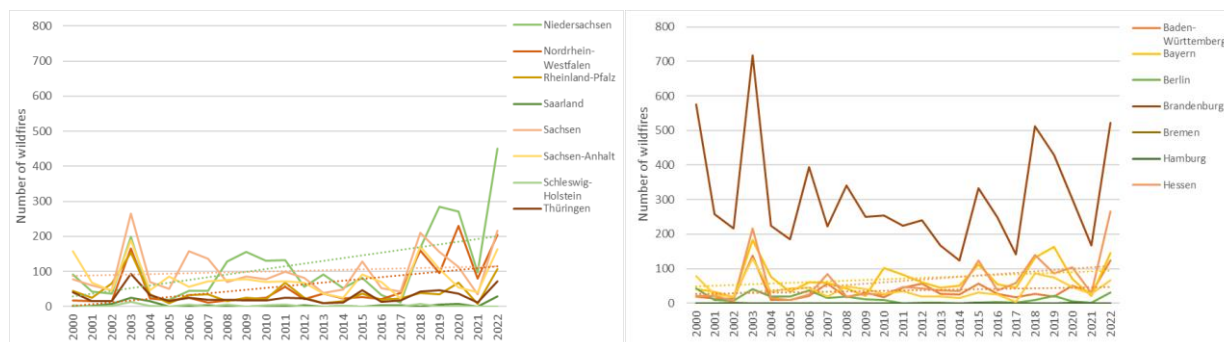


Figure 3. Annual number of wildfires in the German federal states in the period 2000 - 2022. Solid lines - annual number of wildfires, dashed lines - linear trend in the federal states with slightly increasing trend (Source: Bundesanstalt für Landwirtschaft und Ernährung).

B. Drought

Compared to wildfire management, the implementation of response actions related to drought is generally weaker across the Clim4Cast countries (Tab. 2). The best implementation status was observed in Poland, where a well-established drought monitoring system is in place and the legal framework for declaring a drought emergency is operational. Overall, the drought monitoring systems in the Clim4Cast countries can be considered reasonably well-developed, particularly in Czechia, Slovakia, and Poland. However, significant gaps remain, especially in Croatia, where the monitoring capacity and institutional coordination require further development.

A major cross-cutting issue in the region is that monitoring systems are often not integrated into decision-making processes. As a result, the legislative frameworks for drought response tend to be weak or fragmented, lacking clear provisions on process hierarchy, institutional authority, strategic planning, and risk assessment. Consequently, legislation provides limited practical guidance during drought events. For instance, in Czechia, drought information is disseminated through multiple web portals (e.g. Intersucho, CHMI web page etc.), each based on different data sources. These platforms are not easily comparable, and drought categories are inconsistently defined, which hampers the usability of the information in practice and hinders coordinated response.

Beside legislation gaps, there is significant need to improve the communication related to drought across the whole region. This includes not only external communication to the public, but also internal communication among involved stakeholders. Stakeholder discussions confirmed that there is demand on educational and training activities focused on recommended measures, not only as a response to drought occurrence, but preventive measures as well. All Clim4Cast countries are struggling with a lack of impact data resulting from unsystematic impact data collection. Considering the impacts reported within the DHF impact database (Deliverable 1.2.1), most of the impacts in the Clim4Cast countries were related to agriculture. Looking more precisely to these impacts show, that drought influences importantly not only yield losses, or quality change of the crops, but conditions also changes in crop, or land management and influences livestock production through fodder and water supply shortage and livestock selling. The second mostly reported impacts are related to hydrology, where the reduction of river flows and water levels in water bodies dominate. It is also important to mention the impacts on household water supply, because water use restrictions occurred in the Clim4Cast region not only during the extreme drought events on 2003, or 2022, but repeatedly also in years after 2011. Regarding



economical losses due to drought, these caused new or modified legislation in Slovenia in 2000 and in Croatia in 2003, 2011, 2012 and 2022. The lesson learnt from the stakeholder consultations confirm that there are large legislation gaps resulting in unsystematic institutional response and undefined communication flow among data providers, policy-makers and vulnerable stakeholders. This lead to underestimating drought impacts on households, or economy and to insufficient proactive management resulting for example in decrease of irrigable agricultural area in some countries (e.g., in Slovakia; Fig. 4) despite the fact that the frequency of drought events increases and there are statistically significant correlations between drought occurrence and yield losses (Fig. 5). The lack of impact data seems to lead also to weak societal response in form of new or modified legislation in the Clim4Cast countries.

Table 2. An evaluation, at which stage each of seven actions listed in the response phase of the conceptual scheme for proactive response to DHF events has already been implemented within drought management in each country of the Clim4Cast region (green - action fully implemented, yellow - action partly implemented, red - action not implemented).

Topic	Action	Croatia	Poland	Austria	Germany	Slovakia	Slovenia	Czechia
LEGISLATION	12. Implement legal frameworks for declaring DHF event emergencies (see action 1)	Red	Green	Green	Red	Red	Yellow	Yellow
	13. Implement protocol for effective DHF management (activities implemented in each stage of DHF as defined for example in DHF management plans) (see action 3)	Red	Green	Green	Red	Red	Red	Yellow
DATA AND KNOWLEDGE	14. Implement continuous DHF monitoring and integrate advanced DHF forecasting tools including generating and disseminating near-real time DHF status reports	Red	Green	Yellow	Yellow	Green	Yellow	Green
	15. Conduct comprehensive DHF impact assessments across key sectors (such as agriculture, water resources, public health, and infrastructure)	Yellow	Yellow	Red	Yellow	Red	Red	Yellow
COMMUNICATION	16. <i>“external”</i> Provide timely and accurate information to the public about the current and anticipated DHF situation and appropriate response measures that are based on measures identified in the DHF management plans	Yellow	Yellow	Yellow	Yellow	Yellow	Red	Yellow
	17. <i>“internal”</i> Follow defined communication flow and coordination mechanism (see actions 2 and 3), e.g., regular briefings, meetings with DHF committee, national authorities for coordinating actions	Red	Yellow	Yellow	Yellow	Red	Yellow	Yellow
	18. <i>“stakeholders engagement”</i> Engage with predefined set of stakeholders for support with implementation of measures	Red	Yellow	Yellow	Yellow	Red	Yellow	Yellow

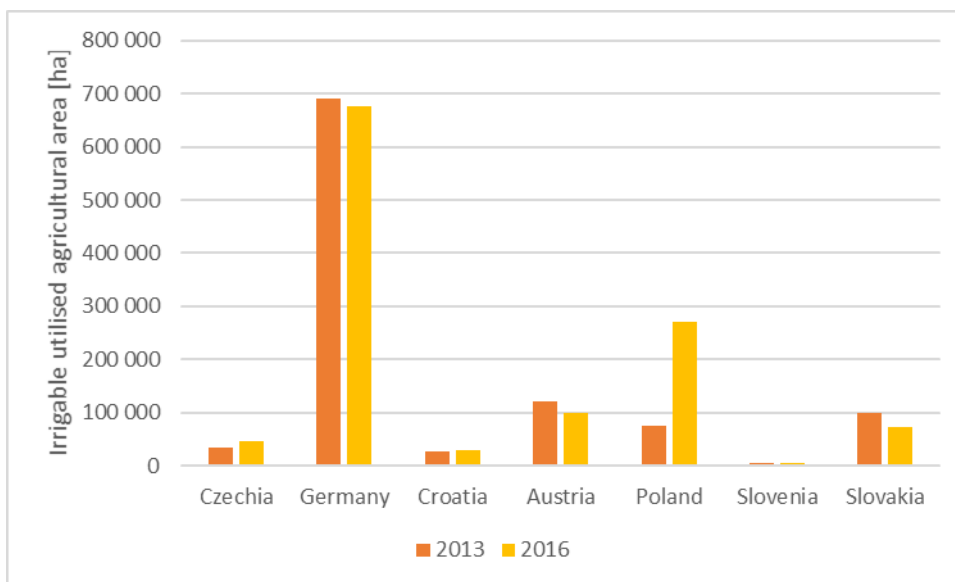


Figure 4. Irrigable agricultural area [ha] in the Clim4Cast countries in years 2013 and 2016 (Data Source: Eurostat).

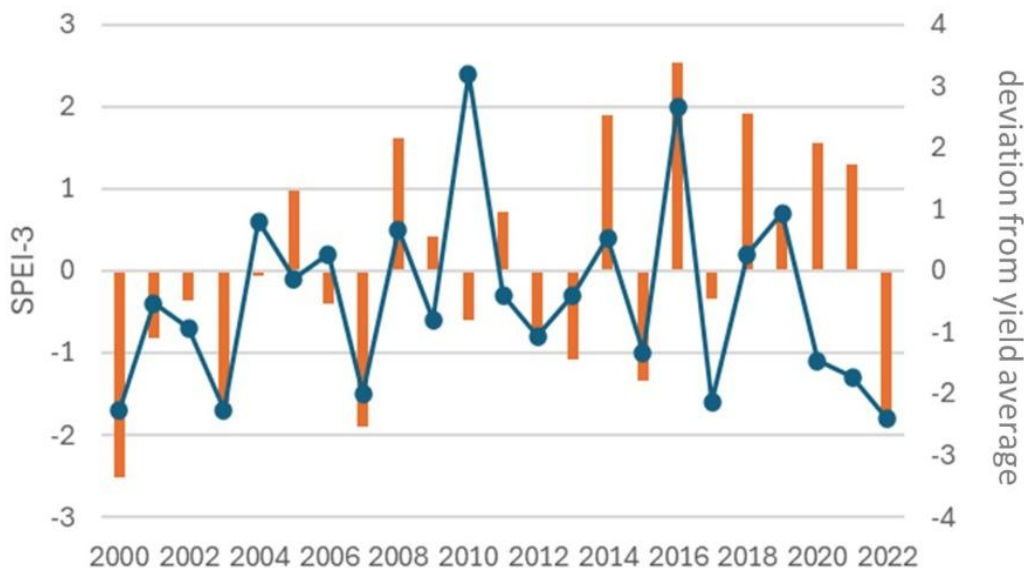


Figure 5. Deviations from average corn yield losses (bars) and 3-monthly Standardized Precipitation and Evapotranspiration Index (SPEI) in July (blue line and dots) in the Nitra Self-governing Region (NUTS3) in the period 2000-2022 (Source: Slovak Hydrometeorological Institute and Statistical Office of the Slovak Republic).



C. Heatwaves

Among all types of DHF events, the weakest institutional response mechanisms were identified in relation to heatwave management. Within the Clim4Cast countries, Croatia demonstrated a relatively better status, although significant limitations remain. While Croatia has established some basic components for heatwave management, institutional cooperation is insufficiently defined. Roles and responsibilities at the national and regional levels are unclear, and cross-border coordination is virtually absent. Moreover, there is a lack of comprehensive impact assessments covering key sectors such as agriculture, public health, water management, and infrastructure, which severely limits the effectiveness of preparedness and response planning. Post-season evaluations and mechanisms for capturing lessons learned are rarely implemented or shared systematically, which hinders continuous improvement and adaptive response development. The lowest level of implementation was reported in Poland, where no legislative framework for heatwave management currently exists across any phase of the disaster management cycle. Construction standards have not been updated to reflect changing climate conditions, and land-use planning regulations fail to address the need for heat-resilient urban design, such as the integration of shaded public spaces. According to stakeholder feedback, heatwaves are not systematically considered in Poland's risk management frameworks, largely due to a lack of scientific studies quantifying their health impacts. There is also no centralised database recording heatwave-related mortality, which contributes to low public awareness and underestimation of risk. A similar situation was reported across the remaining Clim4Cast countries. In addition to weak or absent legislation and the lack of impact-based studies, a deficient or non-existent monitoring and early warning system is a shared problem: in Czechia, no event progression monitoring exists, and information flow to the public and key sectors is poorly defined. In Slovenia, the color-coded warning levels used by different institutions for heat alerts are unclear and not harmonised, creating a risk of public confusion and misinterpretation. In Slovakia, alerts are issued only for high maximum daily temperatures, while critical aspects of heat stress, such as high night-time temperatures or combined heat and humidity, are not considered. As a result, vulnerable population groups—especially elderly people (65+) and young children (<5), may not receive adequate warning. Across the Clim4Cast region, data on heatwave-related health impacts are scarce or entirely missing. Similarly, impacts on agriculture, labour productivity, and other economic sectors are rarely assessed, further weakening the evidence base needed for informed policymaking and adaptation planning. Considering the impacts reported within the DHF impact database (Deliverable 1.2.1), the most of them was related to the human health difficulties. Only some of heatwave impacts were related to agriculture, within which they were related exclusively to the decrease in milk production and the well-being of livestock and animals in Slovakia and Czechia. The impact of crops was not reported among impacts in selected newspapers. The lesson learnt based on stakeholder consultations is that each country has a significant gap in institutional and societal response mechanism related to heatwave events. The gaps are not only in legislation, but also in monitoring and warning systems, evaluating of heatwave impacts and communication flow. Therefore, it is unable to find good practice, which could be applied in other countries of the region. Further, the lack of impact data seems to lead to the underestimation of heatwave impacts on agriculture, energy production and economical losses, which were reported in the DHF impact database only rarely. The possible explanation of this situation could be unawareness of real heatwave impacts on these sectors.



Table 3. An evaluation, at which stage each of seven actions listed in the response phase of the conceptual scheme for proactive response to DHF events has already been implemented within heatwave management in each country of the Clim4Cast region (green - action fully implemented, yellow - action partly implemented, red - action not implemented).

Topic	Action	Croatia	Poland	Austria	Germany	Slovakia	Slovenia	Czechia
LEGISLATION	12. Implement legal frameworks for declaring DHF event emergencies (see action 1)	Yellow	Red	Yellow	Red	Red	Yellow	Red
	13. Implement protocol for effective DHF management (activities implemented in each stage of DHF as defined for example in DHF management plans) (see action 3)	Yellow	Red	Yellow	Yellow	Red	Yellow	Red
DATA AND KNOWLEDGE	14. Implement continuous DHF monitoring and integrate advanced DHF forecasting tools including generating and disseminating near-real time DHF status reports	Yellow	Red	Red	Yellow	Red	Yellow	Yellow
	15. Conduct comprehensive DHF impact assessments across key sectors (such as agriculture, water resources, public health, and infrastructure)	Red	Red	Red	Red	Red	Red	Red
COMMUNICATION	16. <i>“external”</i> Provide timely and accurate information to the public about the current and anticipated DHF situation and appropriate response measures that are based on measures identified in the DHF management plans	Yellow	Red	Yellow	Yellow	Yellow	Yellow	Red
	17. <i>“internal”</i> Follow defined communication flow and coordination mechanism (see actions 2 and 3), e.g., regular briefings, meetings with DHF committee, national authorities for coordinating actions	Yellow	Red	Red	Yellow	Red	Yellow	Red
	18. <i>“stakeholders engagement”</i> Engage with predefined set of stakeholders for support with implementation of measures	Yellow	Red	Red	Yellow	Red	Yellow	Yellow

Heat stress and cardiovascular mortalities

These institutional and informational shortcomings may be particularly concerning in light of the observed relationship between heat-related hazards and human health outcomes. Our preliminary analysis of NUTS-3 regions in Czechia, Austria, and Slovakia revealed that cardiovascular mortality is positively associated with the occurrence of heatwave days (a period of at least three consecutive days exceeding the 99th percentile of the daily maximum temperatures of the May to September season during the reference period), high UTCI (Universal Thermal Climate Index; UTCI above 32 °C) days, and tropical nights (Tmin above 20 °C). UTCI is an equivalent to temperature corresponding to a measure of the human physiological response to meteorological conditions that also takes into consideration the clothing adaptation of the population in response to outdoor temperature. Monthly mortality patterns in most regions of Austria, Czechia, and Slovakia show a pronounced winter maximum, reflecting cold stress, increased respiratory infections, and elevated blood pressure. However, a secondary summer peak is also apparent, particularly during periods of extreme heat. Examples from Prague and Vienna illustrate that this summer peak coincides with heatwave events, high UTCI days, and tropical nights, highlighting the sensitivity of cardiovascular systems to thermal stress. The timing and magnitude of this



peak vary by region, influenced by differences in climate exposure, population health, socio-economic vulnerability, and adaptive capacity. Examples for Vienna and Prague are shown in Figs. 6.

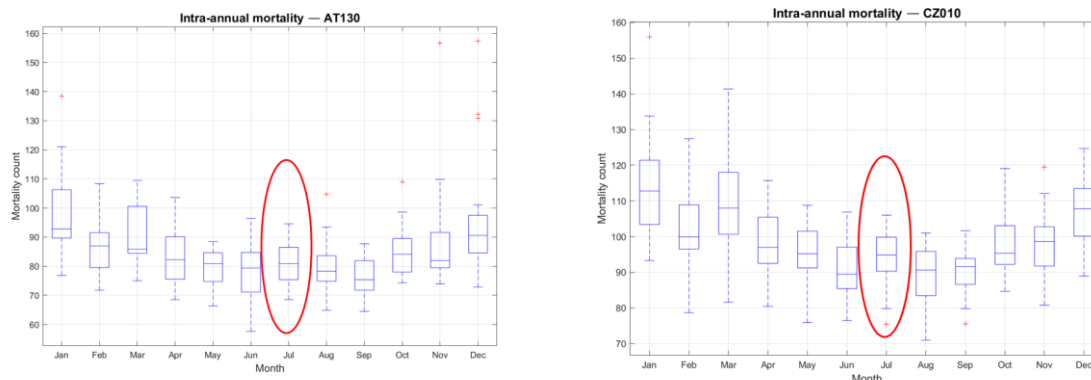


Figure 6. Intra-annual distribution of monthly mortality rates (per 100 000 inhabitants) due to cardiovascular diseases in the AT130 region (Wien, Austria) and in the CZ010 region (Prague, Czechia). Values represent monthly averages over the study period 2000 - 2022, highlighting seasonal variability in cardiovascular mortality with a small secondary peak observed in July.

Years were classified as extreme when values for each hazard exceeded the 75th percentile. Conditional probabilities of high mortality were calculated for each hazard separately and for their simultaneous occurrence. The expected joint probability under statistical independence was obtained by multiplying the individual conditional probabilities for each hazard (Fig. 7 shows the averaged box plots). Figs. 8 and 9 present the spatial distribution of these results: Fig. 8 shows the probability of elevated mortality given that heatwave days in a given year exceed the 75th percentile, and Fig. 9 shows the probability of experiencing elevated mortality in a given summer season when the number of heatwave days, high UTCI days, and tropical nights occur in that particular season is extreme. We found that summer cardiovascular mortalities are linked to heat-stress climatic indices, but worsen with poor socio-economic conditions. Higher mortality was found in regions with higher share of persons at risk of poverty or social exclusion (EUROSTAT 2022). These vulnerable groups face greater exposure and reduced capacity to cope with extreme heat.

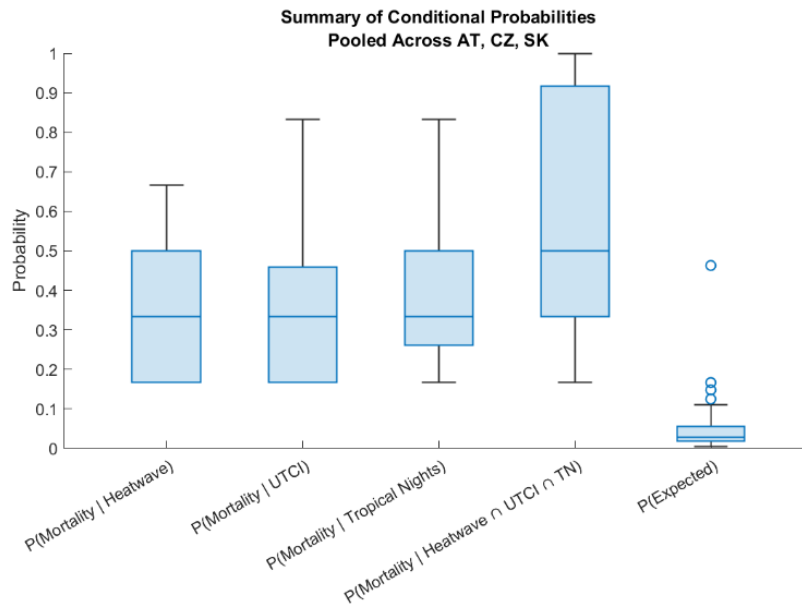


Figure 7. Box plots (averaged over all regions) showing the probability of elevated mortality: (1) $P(\text{Mortality} | \text{Heatwave})$ – probability of high mortality given the number of heatwave days in that season exceeds its 75th percentile, (2) $P(\text{Mortality} | \text{UTCI})$ is the probability of high mortality given the number of high UTCI days exceeds its 75th percentile, (3) $P(\text{Mortality} | \text{Tropical Nights})$ is the probability of high mortality given the number of tropical nights exceeds its 75th percentile, (4) $P(\text{Mortality} | \text{Heatwave} \cap \text{UTCI} \cap \text{TN})$ is probability of a season when elevated mortality exists given all three hazards occur in the same season, and (5) shows the probability of elevated mortality under the assumption of statistical independence, calculated as the product of the marginal conditional probabilities-

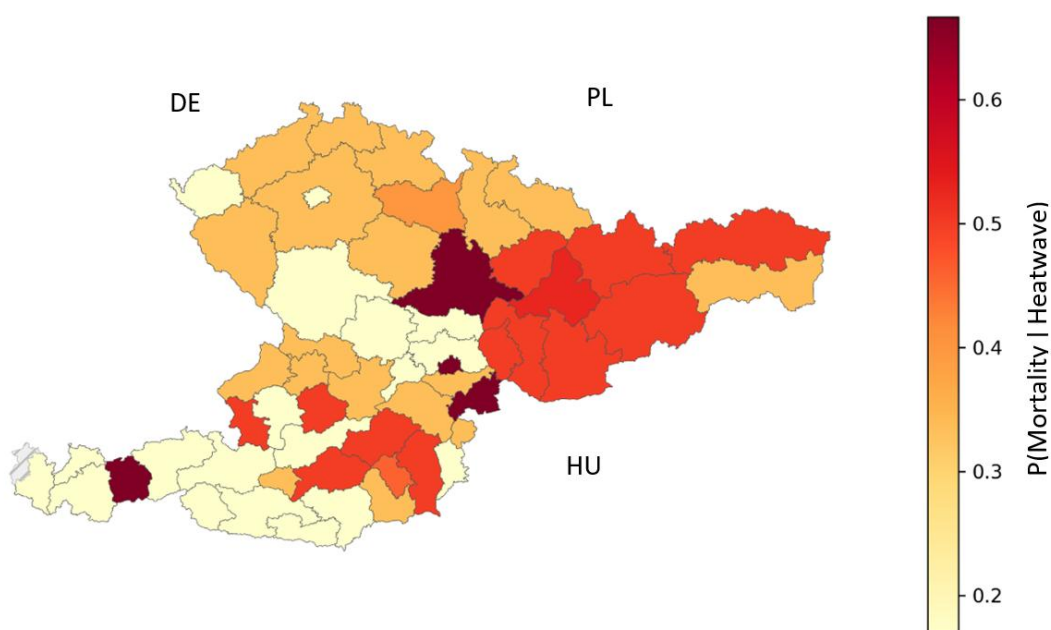


Figure 8. Probability of elevated mortality given heatwave days exceed the 75th percentile in Czechia, Slovakia and Austria.

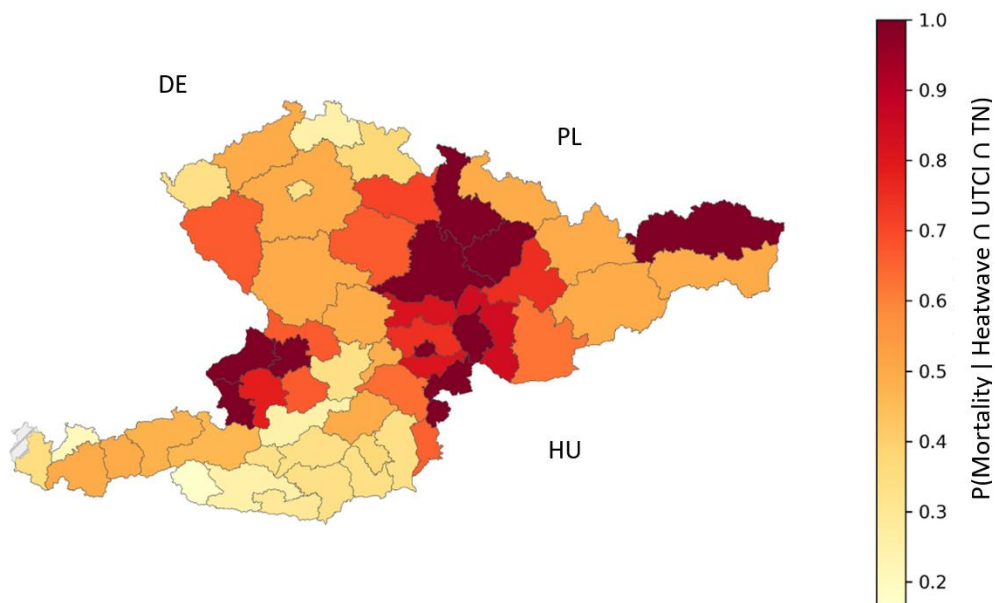


Figure 9. Probability of experiencing a summer season with high mortality when the number of heatwave days, high UTCI days, and tropical nights are high in Czechia, Slovakia and Austria.