

Climate risks in Hungary over the coming decade

A risk profile for 2026–2035,
with an outlook to 2050

TEN-YEAR WINDOW

OUTLOOK

2050



2026

2035

Background document for senior civil servants · Courtesy translation · Budapest, October 2026

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How to navigate this document

Five recurring signs help the reader. They mean the same on every page.

	Position band at the foot of the page Executive summary (ES), decision-makers' part (D), Chapters I–IX, Annexes (A): the dark field is the current chapter, the light ones those already read.		Finding label Next to the key findings at the start of each chapter: where the statement comes from and whether it is new relative to the earlier picture (Chapter I).
¹² (IV.2)	Note and cross-reference The blue superscript points to a note in Annex D, the bracketed reference to a chapter and section. Both are clickable in the PDF.		Numbered action The sectoral recommendations of Chapter IX: the action in bold, followed by the rationale and the chapter referred to.
	Figures and maps The images carry Hungarian labels; the caption below each gives the title, source and note in English. This is a courtesy translation; the Hungarian text is authoritative.		

The reading rules are summarised in Annex **B** and the terms in Annex **C**; section **G.4** explains how to read the figures. Notes and sources are in Annex **D**.

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Foreword

In Hungary, the impacts of climate change are no longer merely a theoretical issue concerning the future, but are also evident in measured data and in the functioning of individual sectors of public administration.

The year 2026 has ruthlessly highlighted the unpleasant fact that Hungary is currently ill-prepared to deal with the threats posed by climate change. The summer of 2026 and the first nine months of the year were the driest since 1901,²⁰⁸ while the summer vapour pressure deficit – that is, the air’s capacity to hold moisture – has increased by 39 per cent since the 1970s. For four key meteorological indicators, our observation series fall outside the range of the current domestic climate projections. Meteorologists have long maintained that past climate is not a good proxy for the future; yet in planning practice, this is still frequently taken as the starting point. This approach is no longer tenable. If it is no longer tenable, what can planning be based on?

This volume examines what we need to prepare for in the period between 2026 and 2035, and also includes an outlook extending to 2050 on the expected trajectory of climate change. It answers this question based on the best available data, while also highlighting where data is lacking, and always distinguishes between what we know, what we can only estimate, and what we currently have no reliable knowledge of.

Given the limited nature of our knowledge, risk analysis is the best approach to take when it comes to planning. The aim of this volume is therefore not to summarise the scientific consensus, but to present the risks that are important from a decision-making perspective, their magnitude and the potential cost of error. It thus also discusses unfavourable but realistically possible outcomes, and deals specifically with those risks that we are not yet able to quantify.

This study is primarily intended for senior professionals in public administration, rather than the general public. As its purpose is specific, it prioritises professional accuracy, even at the expense of accessibility. It sets out the methodological details, uncertainties and shortcomings in the data sources, as all these are necessary for responsible planning decisions. As the report was produced in two months and relied mainly on publicly available data, it does not attempt to provide a comprehensive overview covering all sectors, but focuses on the most critical areas.

EXECUTIVE SUMMARY

The document at a glance

The lead sentences of the executive summary. The details are in the summary and in the chapters referred to.

WHAT THE DOMESTIC MEASUREMENTS SHOW

1	The country is warming faster than official climate projections suggest.	→ II.1 · H.2
2	The decline in water resources is not caused by changes in annual precipitation totals.	→ II.2 · III.1 · III.2 · VII.5
3	Summer drought is reflected in the air’s vapour pressure deficit, not in the length of dry periods.	→ II.2
4	The risk of frost is not disappearing, but merely changing form.	→ II.3 · II.4
5	The same amount of precipitation, but occurring less frequently and more intensely.	→ II.4 · III.3 · III.4
6	The climate classes of the forests have already shifted.	→ II.6

THE BALANCE OF DAMAGE

7	The mortality burden of heat remains hidden in cause-of-death statistics.	→ IV.1 · IV.2
8	Official exposure and vulnerability data have not been updated for a decade.	→ IV.2
9	In agriculture, maize is the crop most sensitive to heat and water shortages.	→ IV.3 · V.2
10	Energy supply and water run into difficulties in the same summer.	→ IV.4
11	There is no official damage assessment.	→ V.1 · V.2

Further parts of the summary: Global trends and the outlook for 2050, Why we need to plan differently, What needs to be done.

Executive summary

This document is a risk analysis. It examines what climate hazards, differing from the usual planning assumptions, may arise in Hungary over the next ten years, between 2026 and 2035; who and what they will affect; and for which decisions they matter. A risk analysis cannot predict exactly what will happen. What can be determined, however, is what we need to prepare for, and which mistake is more costly: unnecessary caution or a failure to prepare. The outlook extends to 2050. The analysis is based on domestic measurement series: the daily data¹ maintained by HungaroMet since 1971, which have been homogenised and interpolated to grid points, as well as data series from the groundwater monitoring network and water gauges. These are compared with two domestic climate projection datasets (KLIMADAT, FORESEE-HUN), as well as with an international decadal climate prediction. Where the models do not even reach current measured conditions, the measured value serves as the starting point for planning. The method is described in Annex G, while the data and the verification of the calculations are set out in section G.6.

What the domestic measurements show

The country is warming faster than official climate projections suggest. Comparing two 20-year periods, the annual mean temperature rose from 9.9 °C in 1971–1990 to 11.5 °C in 2006–2025, while the summer mean rose from 19.3 °C to 21.5 °C. At the same time, the number of extremely hot days reaching 35 °C rose from 0.3 to 4.9 per year, while the number of tropical nights (when the temperature does not fall below 20 °C even at night) increased from 0.4 to 3.6. Over the last five years (2021–2025), there were an average of 8.5 extremely hot days and 6.6 tropical nights per year. Not a single run of the two domestic climate projections reaches the measured annual mean temperature: the median of the runs reaches, 13–16 years later, the level the measurements have already reached. The same applies to the number of days reaching 30 °C (referred to as ‘hot days’ in HungaroMet’s terminology), as well as to spring frost and summer vapour pressure deficit. Data on these two variables are provided only by FORESEE-HUN. For these four indicators, the models underestimate the change; therefore, the starting point for planning is the measured value, while the lower limit of the model range is not the

most probable value but the lowest value still conceivable. This rule does not apply to extremely hot days, the duration of dry spells and intense precipitation; in these cases, the models do not fall below the measured values (H.2, II.1).

The decline in water resources is not caused by changes in annual precipitation totals. Annual precipitation has increased only slightly since 1971, to an extent that is not statistically significant. Comparing two twenty-year periods (1972–1991 and 2006–2025), precipitation in the winter half-year increased from 226 to 255 mm, while that of the summer half-year changed from 351 to 355 mm, and that of the summer months (June–August) fell from 200 to 191 mm. Precipitation during the summer half-year has only declined appreciably in the last five years, standing at 312 mm in 2021–2025. Despite this, groundwater levels are falling in 721 of the 763 wells in the national network of permanent observation wells with a quarter-century-long time series; east of the Danube, this is the case in 98 per cent of the wells, with a median decline of half a metre per decade. In August 2026, 79 per cent of the wells were at their lowest level on record. Two factors are likely to be at play here. One is that groundwater only recharges significantly during winters with abundant rainfall; an average winter barely raises the level, and this was not offset by the slight increase in winter precipitation. The other factor is evaporation: according to a not yet peer-reviewed estimate of the water balance between the Danube and the Tisza, the replenishment resulting from the difference between precipitation and evaporation has fallen to a fraction of what it was in the 1950s. As for how much actual evaporation has increased nationwide, only model estimates are available, and researchers' opinions differ on the significance of evaporation (II.2). Previously, the decline caused by dry years was consistently offset by abundant winters. This cycle has been disrupted east of the Danube: at 84 per cent of wells, water levels have not returned to the 2001–2013 peaks since 2014. In Transdanubia, the decline is slower, while in Western Transdanubia there is no consistent downward trend; in other words, the process is uneven across the country. On the Körös and Maros rivers, in the summer of 2026, every water gauge monitored recorded the lowest flow rate in the data series available since 2000, while on the Danube at Paks, the summer minimum was the lowest value in the 37-year series, amounting to half the usual value. The deeper confined groundwater, which forms the basis of drinking water, has been declining since 2019. We cannot determine whether this is caused by drought or increased abstraction, as a significant proportion of water abstraction is unmeasured (III.1, III.2, VII.5).

Summer drought is reflected in the air's vapour pressure deficit, not in the length of dry periods. The vapour pressure deficit is the air's capacity to take up water vapour, and one of the main drivers of evaporative demand. However, the actual amount of water that evaporates is also determined by the soil's water supply. The summer value of the vapour pressure deficit increased by 73 Pa per decade between 1971 and 2025, and in 2021–2025 it exceeded the 1971–1980 average by 39 per cent. The number of days with a vapour pressure deficit exceeding 1,500 Pa – a level already placing a strain on plants – rose from 19 to 57 per year over the same periods. This is the strongest statistical indicator in this analysis, and none of the 28 domestic model runs reaches its current level. The length of consecutive rain-free periods did not increase between 1971 and 2025 (in the HungaroMet series dating back to 1901, it has increased, and a non-significant decrease since 1981).²⁰⁹ During the 2026 growing season, however, a record was set in the average of the ten stations that have been measuring since 1901 (30.2 days, preliminary data). One year does not constitute a trend, so it cannot be determined at present whether we are seeing an outlier or a turning point. Regardless, the summer of 2026 is the reference event for the sizing of reservoirs and irrigation systems (II.2).

The risk of frost is not disappearing, but merely changing form. The number of frost days fell from 96 to 80 per year between the 1971–1990 and 2006–2025 periods. However, this decrease stems from the beginning and end of winter, that is, from late autumn and early spring days; the number of frost days in April–May has remained unchanged. The date of budburst has moved twelve days earlier, while the date of the last spring frost has remained unchanged. There is no discernible trend in the interval between budburst and the last frost; however, the five-year average for 2021–2025 was higher than in any previous decade. A five-year period can only be compared with decade-long averages with some caution; therefore, this is an indication, not a trend. It is thus too early to scale back frost protection measures. Severe cold spells have become less frequent, but they have not disappeared: temperatures below -20°C occurred at one or more points on the national grid in 13 out of 20 years between 1971 and 1990, and in 7 out of 20 years between 2006 and 2025; in the most recent decade, this was the case in 2017, 2018 and 2021. In 2026, temperatures of -18.3 and $+42.0^{\circ}\text{C}$ were recorded in the same year, so preparations for cold weather cannot be neglected either (II.3, II.4).

The same amount of precipitation, but occurring less frequently and more intensely. The annual total precipitation has not decreased. How-

ever, the number of days with at least 20 mm of rainfall and the rainfall from the wettest days (days above the 95th percentile of wet days) increased by more than 20 per cent between two partially overlapping 30-year periods, 1971–2000 and 1996–2025. The risk of flash floods in small catchment areas is therefore increasing. On the Tisza, however, the number of days on which a level-three flood alert was in force virtually disappeared between the periods 2000–2012 and 2013–2025 (falling from 12 to 1.5 per year in Szolnok, and to zero in Szeged and Tokaj), whereas this was not the case on the Danube. In September 2024, the Danube experienced one of the greatest floods of the century while, in the same month, the Tisza experienced prolonged low flows (II.4, III.3, III.4).

The climate classes of the forests have already shifted. The proportion of area in the beech climate class fell from 5.5 per cent to 2.1 per cent, while that in the hornbeam-oak class fell from 28.9 per cent to 21.0 per cent; nearly a quarter of the country's territory has been reclassified into a drier climate class, and the trend has been towards drier conditions everywhere. Both assessments end in 2010; the warming that has occurred over the past decade and a half is not included. A further, as yet not peer-reviewed ELTE analysis uses a classification system (Thorntwaite) that also takes soil water reserves into account. According to this, the proportion of areas with a semi-arid climate rose from 5 per cent in 1972–1989 to 16 per cent in 1990–2007, and stood at 15 per cent in 2008–2025²¹⁰ (II.6).

Who is affected and what are the costs?

The mortality burden of heat remains hidden in cause-of-death statistics. Based on our own calculations using the Hungarian Central Statistical Office's (KSH) daily mortality data, approximately 2,300 deaths in 2024 can be attributed to heat, while cause-of-death statistics for the same year listed heat as the cause of death in only 27 cases. The excess mortality can also be demonstrated using a different calculation: according to an as yet unpublished analysis by ELTE, there were approximately 1,400 excess deaths during the three weeks of 2024 with the most severe heat-waves, a 20 per cent excess on average nationally, using a daily mean temperature threshold of 27 °C (Péter Szabó, personal communication, October 2026). According to a European estimate, the burden falls almost entirely on those aged 75 and over: in the summer of 2024, there were 1,668 heat-attributed deaths per million inhabitants in this age group, compared with 19 among younger people. The heat burden on those aged 75 and over – that is, the product of the number of extremely hot

days and the size of this age group – was 3.2 times the 1991–2020 level in 2021–2025. The number of cases in emergency care rises by 2 per cent on heatwave days; in districts with low incomes and a shortage of GPs, the impact is one-third to one-half greater. Eighty-eight per cent of social care institutions operate without air-conditioned rooms. The heat alert series ends in 2023, while the emergency series ends in 2017; and there is no domestic monitoring of the elderly, people with chronic conditions, pregnant women and outdoor workers (IV.1, IV.2).

Official exposure and vulnerability data have not been updated for a decade. The vulnerability layer of the official adaptation GIS system dates from 2005–2014, its population projection is from 2011, and its climate layer is based on the previous model generation. Meanwhile, the number of people aged 65 and over has increased by 17 per cent, and in Csongrád-Csanád, Békés and Bács-Kiskun counties, the number of extremely hot days more than tripled in 2021–2025 compared with the 1991–2020 average; in Csongrád-Csanád, for example, it rose from 5.5 to 18.2 per year. In densely populated urban areas, the situation is worse than the national grid suggests, as the grid does not capture the urban heat island effect: 31 tropical nights per year were recorded in the inner city of Szeged, compared with 9 in the outskirts (IV.2).

In agriculture, maize is the crop most sensitive to heat and water shortages. Since 1990, there have been six years in which the average maize yield has been more than 20 per cent below the seven-year rolling median (measured against the previous year's yield, there were ten such years). In each of these years, the shortfall was linked to an unusually hot summer; however, the average yield is just as closely linked to rainfall during the growing season as it is to summer heat. In Békés County, the average yield fell from 6.7 t/ha in 2010–2019 to 4.6 t/ha in 2021–2025, while in Zala County it increased over the same period. In 2026, the preliminary county average in Békés was 1.4 t/ha; nationally, the average maize yield was estimated at around 3 t/ha, following 3.4 in 2022 and 5.3 in 2025 (V.2). Meanwhile, the area under maize cultivation fell by a quarter nationwide, with sunflowers partly taking its place. The 2022 drought caused damage amounting to approximately 2.4 billion euros across six crops. Compensation payments between 2012 and 2024 totalled 162.8 billion forints, 70 per cent of which was due to drought and 14 per cent to spring frost; in 2022, only 80 per cent of eligible claims were paid out. The area at risk of secondary salinisation is of the order of 400,000 hectares, and the process does not reverse of its own accord (IV.3, V.2).

Energy supply and water run into difficulties in the same summer. According to public statements, on 29 July 2026, for the first time in the history of the Paks power station, an entire unit was shut down due to low flows; by early August, only two of the four units were operational. Reports differ on the most severe phase of the shutdown (IV.4). There is no aggregate figure for the proportion of capacity dependent on cooling water, nor for the impact on imports and prices. The water management licence does not assume responsibility for a fully reliable water supply, while energy planning regards this as a given (IV.4).

There is no official damage assessment.² There is no economy-wide aggregate of climate-related damage; the only official macro-estimate is sixteen years old. According to European damage figures, domestic weather-related damage between 1980 and 2024 amounted to 12.8 billion euros, 78 per cent of which occurred in just five years, and only 4.8 per cent of which was insured. A reserve scaled to an average year is therefore insufficient. Figures circulating in public debate, such as ‘water scarcity accounts for 7 per cent of GDP’, have no Hungarian estimate behind them (V.1, V.2).

Global trends and the outlook for 2050

Over the past decade, the planet has warmed faster than at any time since instrumental measurements began. The rate of human-induced warming is 0.27 °C per decade, while the observed warming – filtered for natural fluctuations – has been 0.34–0.42 °C per decade since 2013–2014, depending on the dataset. The Earth’s energy surplus – that is, the rate at which the climate system absorbs heat – has more than doubled over the past two decades. Over the past decade and a half, observed warming has been at the top of the range predicted by the older generation of global models (CMIP5) and in the upper part of the range predicted by the newer ones (CMIP6), although over the entire 1970–2025 period, the average of the newer models overestimates warming by about a quarter.²²¹ Contributing to this acceleration is the fact that, as a result of successful air-quality protection measures, part of the cooling aerosol layer has disappeared, and that terrestrial carbon sinks are weaker than assumed. Domestic projections should be regarded as lower-bound estimates. This is demonstrated by domestic measurements, not by the global picture: the two sets of domestic projections, which are based on the older CMIP5 generation, do not even reach the level of domestic warming already measured (H.2, VI).

For domestic planning by 2050, we recommend three global warming levels. The planning baseline is the continuation of the observed rate of warming, amounting to approximately 2 °C of global warming compared with pre-industrial levels. All facilities operating until 2050 must be able to withstand this. 2.5 °C is the stress-test level: long-lived facilities must also be assessed at this level. 3 °C is the extreme branch, used for thinking through the consequences scenario by scenario. The acceleration is evident across five measured data sets; therefore, the 2 °C assumption is more optimistic than conservative. In Hungary, according to our own estimates, the three levels correspond to annual warming of approximately 1.9, 2.5 and 3.3 °C compared with the 1991–2020 normal, while the global average warms by 1.1, 1.6 and 2.1 °C relative to the same baseline. In a 2.5 °C world, the summer of 2026 would be considered no more than an average summer (VII.1). If warming were to stabilise at around 1.8 °C (favourable scenario) or 1.5–1.6 °C (favourable extreme scenario), this would ease the burden, but planning cannot be based on this, as the carbon budget for the 1.5 °C scenario would be exhausted in three years at current emission levels, while that for the 1.7 °C scenario would be exhausted in twelve years. Europe is warming at twice the global rate; the official domestic temperature figures for 2050 should also be regarded as lower-bound estimates because the projections lag. The Alpine glacier reserves feeding the Danube will roughly halve by 2050; more water is expected in winter, and less reliable flows in summer. Of the seven tipping points affecting Hungary, five have thresholds in or below the 2–2.5 °C range, while the weakening of the Atlantic circulation system³ could make Hungarian winters more extreme (VII).

Why we need to plan differently

The consequences stem not from a slow shift in averages, but from the crossing of thresholds. With a 1.2 °C rise in the annual mean temperature, for example, the annual number of extremely hot days has increased from 2.8 to 8.5 (1991–2020 and 2021–2025 respectively). The damage also occurs in just a few exceptional years. The deterioration runs at two speeds. Slow erosion – such as the quarter-century-long decline in groundwater levels or the reduction in the number of days with snow cover from 22 to 6 – is not conspicuous in any single year, particularly when measured against the recent past. The sudden turn then hits this already weakened system. A case in point is the summer of 2026, when summer rainfall across the country totalled 74 mm – barely more than a third of the long-term average and 27 mm less than the previous driest

summer on record, in 1952 – while heatwaves, drought, low flows and power station output curtailment occurred simultaneously. Planning that treats hazards separately regularly underestimates such compound events. As 96 per cent of our water supply comes from abroad, droughts in upstream countries also have a direct impact on us. Particularly dangerous is the risk of a spiral, in which a series of incidents and crisis management divert funds and attention away from prevention (VIII.1–VIII.3).

Planning must therefore not be based on the most likely future, but on what could cause unacceptable damage and which of that can be avoided. The tools for this are the naming of a reasonable worst-case scenario, the reverse stress test (what combination of factors would lead to system failure), pre-defined decision points, and the preservation of redundancy, diversity and isolatability – features that are the first to be sacrificed in systems optimised for cost-effectiveness (VIII.4, VIII.5).

We anticipate three scenarios for the coming decade. The basis for our planning is that global warming will continue; winter replenishment is not expected to offset summer depletion, as has been the case over the past quarter of a century; and reserves will continue to decline slowly. The design case is a less likely but reasonably possible sequence of events, in which two or more consecutive dry winters are followed by a series of heatwaves and power station load reductions due to low flows. In these same years, for reasons unrelated to the dry winters, spring frost damage may also affect agriculture. Twelve pre-defined warning signs between 2027 and 2031 will show which way the decade is heading, ranging from winter precipitation to well-level minima and tropical nights, through to the link between heat and mortality. However, these can only be used if we specify in advance, for each one, what decision will be triggered when the threshold is crossed (VIII.6, VIII.7). The indicators for the early years may be distorted by the El Niño expected to develop in the autumn of 2026, which is forecast to be of historic strength. It will cause a one-off rise in global temperatures, but its impact in Hungary cannot be predicted in advance; so no switch between scenarios should be made on the basis of a single El Niño year (VIII.7).

What needs to be done

Three rules apply across all sectors. (1) For temperature, the number of days reaching 30 °C, spring frost and the summer vapour pressure deficit, the measured value is the starting point, while the lower limit of the model range is the minimum conceivable value. (2) Design is not based

on the mean value, but on an unfavourable yet realistic scenario, namely two consecutive drought years with heat and low flows, which may also be accompanied by spring frost damage as an independent hazard. (3) Facilities intended to remain operational beyond 2050 must be designed for at least 2 °C, with a 2.5 °C stress test, and this level must be enshrined in legislation (IX.1). The most important of the sector-specific actions are:

- **Water management:** making water abstraction measurable is the least costly step and a prerequisite for all other decisions. Water from the winter half-year must be retained in the landscape, and the sequence of interventions must be determined on a regional basis, based on the combined deterioration of river flows, groundwater levels and average crop yields. The reference event for the sizing of reservoirs and irrigation systems is the summer of 2026 (IX.2).
- **Agriculture:** the vapour pressure deficit should be included among planning and support indicators; the expansion of irrigation is conditional on the water balance and water quality; the reduction in frost protection capacity is premature; and it must be assessed how much damage the compensation system can withstand in two consecutive drought years (IX.3).
- **Forestry:** planting and tree species selection should be geared towards a drier climate class, and the climate class map must be updated with post-2011 data (IX.4).
- **Energy:** the reduction in output due to low flows should be included in the sensitivity analysis of system design, using the frequencies observed in the measured flow series, while peak demand should be planned for the simultaneous occurrence of heatwaves and low flows (IX.5).
- **Health and social care:** heatwave alerts and care planning should be based on four target groups; the primary indicator should be the heat burden on those aged 75 and over; the link between heat and mortality must be continuously monitored; and updating the heat risk map is a quick, low-cost step (IX.6).
- **Buildings and infrastructure:** mandatory summer overheating requirements for new and significantly refurbished buildings; prioritising the heat-proofing of buildings providing care for the elderly; and mandatory climate risk assessments for all publicly funded facilities with a lifespan of more than ten years (IX.7).
- **Local authorities and disaster management:** local heat action plans, initially in counties designated following a combined assessment of heat burden and excess mortality during heatwaves; rainwater drainage in settlements at risk of flash floods; and an exercise for the compound

stress year (drought, heatwave, low flows and energy supply disruptions in the same year), as well as an annual assessment of the twelve warning signs by a designated officer (IX.8).

- **Finance:** an official national economic loss account, a budgetary reserve for rare years of major damage, the extension of financial stress tests to physical risks, a loss financing strategy, and an examination of compulsory, premium-based disaster damage insurance. In the event of a once-in-a-century flood, approximately 936 million euros would remain uncovered after the domestic reserve and the Solidarity Fund (IX.9).
- **Data and measurement:** updating the vulnerability layers of the official adaptation geoinformation system (NATÉR); a public list of the climate thresholds that the public administration wishes to avoid exceeding; the integration of decadal predictions into 5–10-year planning cycles; supplementing existing air humidity measurements in the boundary layer (the layer of air a few hundred metres above the ground) and at sector-specific monitoring sites, as well as establishing a national soil moisture monitoring network in the root zone with a designated data custodian (IX.10, IX.11).
- **Governance:** a five-year implementation programme with a budget and designated responsible parties to accompany the adaptation strategy; a national climate risk report every five years; a standardised planning temperature level in all sectoral plans; and the inclusion of climate risk in a national risk picture shared with the other hazards (IX.12).

This analysis does not provide estimates of drought damage to the national economy, return periods, a complete water balance, the attribution of individual events, or an aggregate ‘cost of inaction’. The limits of the analysis are listed in section H.4 and Annex E.



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What must be decided now

Following the executive summary, this section highlights which decisions cannot be postponed and what action is required in each sector. It does not contain any new data. The actions are drawn from Chapter IX, where the rationale for them can be found; the table at the beginning of the chapter classifies all 66 actions according to the timing of the decision and the confidence in the evidence supporting them. This classification reflects the authors' judgement. No responsible institution is named alongside the actions; the designation of the responsible body is a matter for the government.

What cannot wait

The window for seven decisions is currently open. Once it closes, there will be no further opportunity until the next cycle.

- **Mandatory summer overheating requirements are needed for new and significantly refurbished buildings.** Window: the deadline for transposing the Energy Performance of Buildings Directive expired on 29 May 2026; transposition is currently underway (IX.7, 1.).
- **The adaptation strategy must be accompanied by a five-year implementation programme, with a budget and designated responsible parties for each action.** Window: Climate Act; a decision by the National Assembly is expected in November–December 2026 (IX.12, 1.).
- **A national climate risk report should be produced every five years, and the implementation programme should be aligned with this.** Window: Climate Act, November–December 2026 (IX.12, 2.).
- **A uniform temperature rise level for planning purposes must be established, to which all sectoral plans and standards refer.** Window: Climate Act or its implementing regulation, November–December 2026 (IX.12, 3.).

- **Climate risk must be assessed in a national risk picture shared with the other hazards, with a designated coordinator.** Window: Climate Act and the national risk assessment framework (IX.12, 5.).
- **Budgetary reserves should be planned to allow for rare years of major damage.** Window: the 2027 budget (IX.9, 2.).
- **Budgetary provisions for adaptation must be identified.** Window: the 2027 budget (IX.9, 10.).

Ten decisions will have consequences for decades to come: whatever is built or installed now will remain in operation for decades. For these, the design level must be chosen now in accordance with point IX.1.

- **Facilities that will remain in operation beyond 2050 must be designed for at least 2 °C of global warming, with a 2.5 °C stress test.** (IX.1, 3.)
- **When sizing reservoirs and irrigation systems, the summer of 2026 is the reference dry period.** (IX.2, 4.)
- **The statutory hierarchy of water restrictions must also be incorporated into capacity and investment planning.** (IX.2, 6.)
- **Plans for the Danube up to 2050 must take into account higher water flows in winter and more uncertain flows in summer.** (IX.2, 8.)
- **For new or expanding capacities dependent on cooling water, the summer water flow of 2026 must be used as a stress test.** (IX.5, 3.)
- **In settlements within small catchment areas at risk of flash floods, rain-water drainage must be adapted to the measured changes.** (IX.8, 2.)
- **The planning of municipal water supply must take into account the climate sensitivity of drinking water sources.** (IX.8, 3.)
- **Buildings caring for people aged 75 and over must be made heat-resistant as a priority, and cooled communal spaces must be designated in settlements.** (IX.7, 3.)
- **When selecting crops and varieties, heat tolerance and frost tolerance must be considered together.** (IX.3, 4.)
- **Afforestation and the selection of tree species should be based on the drier climate class.** (IX.4, 1.)

Of the remaining actions, 35 are low-cost or no-cost steps that are right in every scenario for the coming decade and are often prerequisites for other decisions, such as measuring water abstraction or updating data layers. Ten have a later decision window, and for four all that needs to be fixed now is the signal that will trigger them. The full list can be found at the beginning of Chapter IX.

Rules applicable to all sectors

- For the four most important indicators, the measured value, rather than the model, serves as the starting point. (IX.1, 1.)
- Preparedness must be scaled to the unfavourable but realistic scenario. (IX.1, 2.)
- Facilities that will remain in operation after 2050 must be designed for at least 2 °C of global warming, with a 2.5 °C stress test. (IX.1, 3.)
- It is too early to scale back cold-weather preparations. (IX.1, 4.)

Sector sheets

Each sheet answers three questions: what is the risk, which three figures illustrate it, and what are the most important actions to take. Alongside the figures, we specify the chapter where the methodology and uncertainties can be found.

Water management

THE RISK

Water resources are dwindling, but not because of lower annual rainfall. Groundwater only replenishes significantly during winters with abundant rainfall; east of the Danube, this cycle has been disrupted since 2014. Deeper confined groundwater, which provides around a third of the drinking water supply, has been declining since 2019, and it is unclear how much of this is due to drought and how much to abstraction, as the majority of water abstraction is unmeasured.

KEY FIGURES

- East of the Danube, groundwater levels are falling in 98 per cent of wells (III.1);
- In August 2026, 79 per cent of wells were at the lowest level of their own record (III.1);
- drainage channels divert an average of around 1.77 billion cubic metres of water annually from drought-prone plains (IV.3).

KEY ACTIONS

- 1** Water abstraction must be made measurable even where it is not currently measured. (IX.2, 1.)
- 2** Water from the winter half-year must be retained in the landscape. (IX.2, 2.)
- 3** The sequence of interventions must be determined on a regional basis. (IX.2, 3.)
- 4** When sizing reservoirs and irrigation systems, the summer of 2026 is the reference dry period. (IX.2, 4.)

A further four actions and the rationale for each: IX.2.

Agriculture

THE RISK

Maize is the most sensitive crop. The strongest measured indicator of summer drought is the air's vapour pressure deficit, that is, the rise in evaporative demand. The risk of frost has not disappeared: the number of frost days in April–May has not changed, while budburst has moved twelve days earlier.

KEY FIGURES

- In Békés County, the average maize yield fell from 6.7 t/ha in 2010–2019 to 4.6 t/ha in 2021–2025 (III.1); according to preliminary county data, it stood at 1.4 t/ha in 2026 (V.2);
- the summer vapour pressure deficit increased by 73 Pa per decade between 1971 and 2025 (II.2);
- in 2022, compensation covered only 80 per cent of eligible claims (IV.3).

KEY ACTIONS

- 1** The vapour pressure deficit (the air's vapour-holding capacity) should be included among the indicators used in agricultural planning and subsidy criteria. (IX.3, 1.)
- 2** The expansion of irrigation must be conditional on the water balance and water quality. (IX.3, 2.)
- 3** The reduction in frost protection capacity is premature. (IX.3, 3.)
- 4** When selecting crops and varieties, heat tolerance and frost tolerance must be considered together. (IX.3, 4.)

A further two actions and the rationale for each: IX.3.

Forestry

THE RISK

The climate classes of forests have already shifted towards drier conditions. The two domestic assessments end in 2010; the warming that has occurred over the past decade and a half is not included in them.

KEY FIGURES

- 23 per cent of the grid cells in the official geospatial data layer have been reclassified into a drier climate class (II.6);
- the proportion of the area in the beech forest climate class fell from 5.5 per cent to 2.1 per cent between 1961–1990 and 1981–2010 (II.6).

KEY ACTIONS

- 1** Afforestation and tree species selection should take the drier climate class into account. (IX.4, 1.)
- 2** The forestry climate class map must be updated with post-2011 data. (IX.4, 2.)

Justification: IX.4.

Energy

THE RISK

Energy supply and water are both at risk in the same summer. There is no aggregate figure for the proportion of capacity dependent on cooling water, and the assumptions underlying water management licences and energy planning differ.

KEY FIGURES

- according to public statements, on 29 July 2026, for the first time in the history of the Paks power station, an entire unit was shut down due to low flows (IV.4);
- At Paks, on 8 October, the Danube's average daily flow rate fell to 613 m³/s (preliminary, operational data) (VII.5);
- In the licence for the Tiszaújváros power station, the water authority does not accept responsibility for ensuring a fully reliable water supply (IV.4).

KEY ACTIONS

- 1** The reduction in output due to low flows must be factored into the design studies for the electricity system. (IX.5, 1.)
- 2** The assumptions underlying water management licensing and energy planning must be harmonised. (IX.5, 2.)
- 3** For new or expanding capacities dependent on cooling water, the summer water flow of 2026 must be used as a stress test. (IX.5, 3.)
- 4** Peak demand planning must take into account the simultaneous occurrence of heatwaves and low flows. (IX.5, 4.)

Justification: IX.5.

Health and social care

THE RISK

The mortality burden of heat remains hidden in cause-of-death statistics and predominantly affects those aged 75 and over. There is no national monitoring of other at-risk groups.

KEY FIGURES

- according to our own estimates, around 2,300 deaths in 2024 can be attributed to heat, while cause-of-death statistics recorded 27 cases (IV.1);
- in Hungarian cities, more than half (56 per cent) of heat-related deaths are a consequence of anthropogenic warming; in Budapest, this figure was 76 per cent in 2025 (IV.1);
- the heat burden on those aged 75 and over (the product of the number of extremely hot days and the size of the age group) rose from 2.1 million to 6.8 million person-extremely-hot-days, a 3.2-fold increase, between 1991–2020 and 2021–2025 (IV.2);
- the official heatwave vulnerability layer is based on data from 2005–2014 (IV.2).

KEY ACTIONS

- 1 Preparations for heat should focus on four target groups: the elderly, people with chronic conditions and those who are bedridden, pregnant women and young children, and outdoor workers. (IX.6, 1.)**
- 2 The heat alert system must not be dismantled. (IX.6, 2.)**
- 3 The link between heat and mortality must be continuously monitored. (IX.6, 3.)**
- 4 The heat risk map must be updated. (IX.6, 4.)**

One further action and the rationale for each: IX.6.

Buildings and infrastructure

THE RISK

The majority of the building stock will still be standing in 2050. The EU Energy Performance of Buildings Directive prescribes adaptation only as a factor to be taken into account; therefore, the scope for action in managing summer overheating lies in the national transposition. In densely populated urban areas, the situation is worse than indicated by the national grid, as the grid does not reflect the urban heat island effect.

KEY FIGURES

- Between 2016 and 2025, an average of 31 tropical nights per year were recorded in the inner city of Szeged, compared with 9 in the outskirts (IV.2);
- according to the United Kingdom's independent assessment, 92 per cent of existing homes could overheat at 2 °C of warming; there are no domestic estimates (IX.7);
- first-generation European structural design standards must be withdrawn by early 2028 (IX.7).

KEY ACTIONS

- 1** Mandatory summer overheating requirements are needed for new and significantly refurbished buildings. (IX.7, 1.)
- 2** Shading, night-time ventilation and passive cooling should also be eligible for funding under renovation grants for existing buildings. (IX.7, 2.)
- 3** Priority should be given to making buildings caring for people aged 75 and over heat-resistant, and cooled communal spaces should be designated in settlements. (IX.7, 3.)
- 4** Climate data used in building and structural design must be aligned with measured values. (IX.7, 4.)

A further three actions and the rationale for each: IX.7.

Local authorities and disaster management

THE RISK

The risks of heat, flash floods and water supply appear at settlement level, and that is where they are most uneven. The summer of 2026 showed what a compound stress year looks like: drought, heatwaves, low river levels and disruptions to the energy supply all occurring simultaneously.

KEY FIGURES

- The annual number of extremely hot days in Csongrád-Csanád rose from 5.5 to 18.2, in Békés from 5.1 to 17.4, and in Bács-Kiskun from 4.4 to 14.5 between 1991–2020 and 2021–2025 (IV.2);
- however, excess mortality during weeks of intense heatwaves is highest in Tolna (35 per cent), Baranya (28 per cent) and Jász-Nagykun-Szolnok (26 per cent) counties, while in Bács-Kiskun it stands at 25 per cent, in Békés at around 24 per cent, and in Csongrád-Csanád at around 20 per cent (2015–2025) (IX.8);
- the official system classifies 367 of the 2,120 mountainous and hilly catchment areas as being at high risk of flash floods (III.5);
- of the 1,495 settlements assessed across the areas served by the ten major water utility providers, 421 fall into the 'highly vulnerable' category (III.5).

KEY ACTIONS

- 1 Local heat action plans must first be updated in the most heavily burdened counties. (IX.8, 1.)
- 2 In settlements within small catchment areas at risk of flash floods, rainwater drainage must be adapted to the measured changes. (IX.8, 2.)
- 3 Planning for municipal water supply must take into account the climate sensitivity of drinking water sources. (IX.8, 3.)
- 4 Disaster preparedness exercises should take the compound stress year as their basis. (IX.8, 4.)

A further two actions and the rationale for each: IX.8.

Finance and budget

THE RISK

There is no official damage assessment, and it has not been decided who will pay for major damage. Damage occurs in a few exceptional years, so reserves calculated for an average year are insufficient.

KEY FIGURES

- Between 1980 and 2024, weather and climate-related damage amounted to 12.8 billion euros at 2024 prices, 78 per cent of which occurred in just five years (V.2);
- 4.8 per cent of the damage was insured (V.2);
- according to a 2021 European model, in the event of a flood with a 1 per cent annual probability, approximately 936 million euros would remain uncovered (IX.9).

KEY ACTIONS

- 1** An official national economic loss account must be established. (IX.9, 1.)
- 2** Budgetary reserves must be planned to account for rare years of major damage. (IX.9, 2.)
- 3** International damage figures should only be used with a domestic basis or together with their source. (IX.9, 3.)
- 4** Financial stress tests must also be extended to cover physical climate risks. (IX.9, 4.)

A further six actions and the rationale for each: IX.9.

Data, measurement and modelling

THE RISK

Official exposure and vulnerability data have not been updated for a decade, while domestic projections remain below the measurements on four indicators. National soil moisture trends can currently only be estimated using models.

KEY FIGURES

- the vulnerability layer of the official adaptation GIS system dates from 2005–2014, while the population projection is from 2011 (IV.2);
- the median of the runs of the two domestic projections reaches, 13–16 years later, the annual mean temperature already measured (H.2);
- of the twelve warning signs, no data custodian has been designated for measuring soil moisture in the root zone (VIII.7).

KEY ACTIONS

- 1** The exposure and vulnerability data layers must be updated. (IX.10, 1.)
- 2** The decadal climate prediction must be incorporated into the 5–10-year planning cycles. (IX.10, 2.)
- 3** A public, specified list of climate thresholds must be adopted; in other words, it must be established which climate thresholds the public administration wishes to avoid exceeding. (IX.10, 3.)
- 4** The data custodians for the warning signs must be designated. (IX.10, 4.)

A further five actions and the rationale for each: IX.10, IX.11.

Adaptation planning and governance

THE RISK

A governance framework is required to implement these actions: a five-year implementation programme, a five-yearly risk report, a standardised planning warming level and a common national risk picture. For most of these decisions, the window is open now, with the Climate Act.

KEY FIGURES

- the planning baseline under point IX.1 is global warming of approximately 2 °C around 2050, with a 2.5 °C stress test (VII.1);
- the National Assembly is expected to decide on the Climate Act in November–December 2026.

KEY ACTIONS

- 1** The adaptation strategy must be accompanied by a five-year implementation programme, with a budget and designated responsible parties for each action. (IX.12, 1.)
- 2** A national climate risk report should be produced every five years, and the implementation programme should be aligned with this. (IX.12, 2.)
- 3** A uniform temperature rise level for planning purposes must be established, to which all sectoral plans and standards refer. (IX.12, 3.)
- 4** The order of the actions should be set according to public, pre-defined criteria. (IX.12, 4.)

One further action and the rationale for each: IX.12.



Analytical part

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The following chapters contain the evidence supporting the above findings and actions, together with the methodology, data and treatment of uncertainty.

How to interpret the figures

The methodological foundations of the analytical chapters are discussed in Annexes G and H. The following rules are sufficient for interpreting the figures correctly; for each, we provide the section number in the annex where further details can be found.

- **The rule for the planning minimum:** if not even the most extreme model member reaches the measured value, the lower limit of the model range is not a conservative estimate but a lower bound, and the planning minimum is the value already observed. This is the most important methodological decision in this document. The rule must be validated for each indicator: it holds for four indicators – temperature, the number of days reaching 30 °C, spring frost (where it holds only for the 14 runs of the moderate scenario) and the vapour pressure deficit – but not for several others. The rule is not a criticism of the models: the discrepancy between model and measurement can be corrected ([G.6](#), [H.2](#)).
- **The three components of risk:** risk is not the same as hazard, but rather the product of hazard, exposure and vulnerability. The points of intervention lie on the vulnerability side, and this layer is accessible and quick and cheap to update ([G.2](#)).

- **The reasonable worst-case scenario:** the basis for sizing is not the most likely outcome, but the worst case that remains once highly improbable variants are excluded. This is not a forecast, but a framework enabling proportionate planning (G.3).
- **The more costly error:** in a planning context, failure to act – not preparing for what then happens – is more costly than a false alarm, because the consequences of a missed investment span decades and are, in part, irreversible. This is a value judgement, not a scientific finding (G.5).
- **Reference period and threshold index:** every figure makes sense only in conjunction with its reference period and time window; figures based on two different reference periods cannot be directly compared. Threshold indices, such as the number of extremely hot days, are calculated at each grid point and only then averaged (G.6, Annex B).
- **Significance: only results** that reach the threshold corrected for the size of the test family (Bonferroni correction) are classified as ‘significant’. The other results are presented descriptively, showing the magnitude of the change, the confidence interval and the p-value. The correction is stricter than necessary, so results that fail it should be treated not as noise but as insufficiently substantiated (Annex B).
- **What this document does not provide:** it does not report return periods, the attribution of individual events or aggregate national economic damage figures, nor does it predict what the summer of a given year will be like (H.4).



What is new?

The basic tenets of the climate debate in Hungary – the IPCC AR6 framework, the 1.5-degree threshold, tipping points, the intensification of heatwaves, and increasingly extreme precipitation – **are largely correct**. Our analysis does not refute these. Where we present new findings, the novelty usually lies not in the direction of change, but in its magnitude, timing or the underlying mechanisms, and most notably in the policy implications.

The points of agreement are as follows. The trend in heatwaves, the shift in precipitation patterns and – most notably – the finding by Hungarian researchers that identifies the increase in the evaporation-evapotranspiration deficit as the common root cause of drought, heatwaves and flash floods are consistent with our own results. Regarding the latter, however, we must point out that the vapour pressure deficit (VPD, a quantity describing the state of the air and calculated from measurements) and the reference evapotranspiration (ET_0 , an indicator calculated for a standard grassland area) are not the same, and their rates of increase also differ. Whenever we discuss evaporation, we specify which of the two is meant.

The two tables below illustrate this difference. The first lists what is already well known, as confirmed by the IPCC’s Sixth Assessment Report (AR6, 2021–2023), and what this analysis also supports with domestic data.⁴² The second table lists what is new or a significant shift relative to the first, with the source type indicated: international literature published after the completion of AR6, our own domestic measurements, and institutional data gaps (missing official damage estimates, outdated vulnerability data). A numerical comparison of the global indicators with the AR6 findings can be found in the table in Section VI.6.

Table A – Well known: also established by AR6

	Item	Where
A1	Human-induced warming is continuing, and the land is warming faster than the ocean	VI.1 (warming), VI.6 (land–ocean ratio)
A2	Heatwaves are becoming more frequent and more intense	II.1
A3	Intense precipitation is intensifying	II.4, III.4
A4	Increasing evaporative demand is one of the driving forces behind agricultural drought	II.2
A5	Heat increases illness and mortality	IV.1
A6	Aerosol pollutants have masked part of the warming	VI.2
A7	Once carbon dioxide emissions cease, global temperatures will largely stabilise	VI.6
A8	A weakening of the Atlantic Meridional Overturning Circulation (AMOC) is likely; its future remains uncertain	VI.5

Table B – New or significant shifts

	Item	Source type	Where
B1	The Earth's energy balance surplus has roughly doubled over two decades, and the models account for only about half of the 2023 value; however, the annual values remain within the model range	Post-AR6 international literature	VI.1
B2	The rate of anthropogenic warming is the highest in the instrumental record	Post-AR6 international literature	VI.1
B3	The terrestrial carbon sink is weaker than previously recorded, and global warming is further weakening it	Post-AR6 international literature	VI.3
B4	Heatwave extremes in Western Europe are intensifying more rapidly than predicted by models; atmospheric circulation accounts for part of this discrepancy	Post-AR6 international literature	II.5

	Item	Source type	Where
B5	A significant proportion of European summer drought is circulation-driven – a larger share for modelled soil moisture, a smaller share for vapour pressure deficit – so the statement based on evaporative demand is the most robust	Post-AR6 international literature	II.2
B6	The proportion of rapidly developing droughts (flash droughts) is increasing worldwide, and the domestic indicator set does not measure this	Post-AR6 international literature	H.4
B7	Hungarian heat-related mortality figures for 2022–2024, by age group; improvements in life expectancy may mask the climate-induced increase	Post-AR6 international literature	IV.1
B8	The scientific literature is divided on the future of atmospheric blocking	Post-AR6 international literature	II.5
B9	Decadal climate predictions are available, with measured skill	international product, domestic verification	H.3, II.1
B10	For four indicators – temperature, days reaching 30 °C, spring frosts, and vapour pressure deficit – the bottom of the domestic model range is a lower bound, while the observed value is the planning minimum	own domestic measurements	H.2, II.1–II.3
B11	Groundwater recharge is limited to winters with abundant precipitation; the intervention point is the winter half-year	own domestic measurements	III.1
B12	There is no trend in the duration of dry spells up to 2025; the 2026 growing season set a record (ten stations, since 1901)	own domestic measurements	II.2
B13	Groundwater levels are falling in the Great Plain and Central Transdanubia, but not in Western Transdanubia; the Körös and Maros rivers reached the lowest point in the measurement series in 2026	own domestic measurements	III.1

	Item	Source type	Where
B14	Extremes in both directions within a single year (2026: –18.3 °C and +42.0 °C), and even within a single month (September 2024: flooding on the Danube and low flows on the Tisza)	own domestic measurements	II.4
B15	Heat stress on those aged 75 and over in 2021–2025 was 3.2 times the 1991–2020 level	own domestic measurements	IV.2
B16	The impact of heat on mortality is immediate, and most of it is not merely deaths brought forward; in 2024, approximately 2,300 deaths were attributable to heat, while cause-of-death statistics recorded 27 heat-related deaths	own domestic measurements	IV.1
B17	Official geospatial products are out of date in both vintage and model generation; vulnerability data are even more out of date than hazard data	institutional gap	III.2 , IV.2
B18	There is no official account of damage to the Hungarian national economy	institutional gap	V.1
B19	The standard EU drought estimate projects a milder drought than observations indicate	conflicting sources	V.3

Of the items listed in the table, three shift or save investment spending: winter recharge, the duration of dry periods and the spatial distribution of groundwater (B11–B13). The vulnerability data are the easiest to remedy, by updating them (B17).



Physical hazards, 2026–2035

SECTIONS OF THIS CHAPTER

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KEY FINDINGS

New – domestic measurements	For four indicators – temperature, the number of days reaching 30 °C, spring frost and the vapour pressure deficit – none of the domestic regional model runs reaches the observed value; for temperature and the number of days reaching 30 °C, this is consistently shown by both FORESEE-HUN and HungaroMet’s KLIMADAT; for these, the observed value is the planning minimum, while the lower end of the model range serves as the lower limit.
New – domestic measurements	There was no trend in the duration of dry periods up to 2025 (although a record was set in the 2026 growing season, based on the average of the ten stations that have been recording since 1901); regarding the level of intense precipitation and the number of days reaching 35 °C, the model does not fall short of the measurements; in these cases, the measured trend is the guiding factor.
New – international product, verified domestically	The decadal climate prediction system tracks summer temperatures well, but this derives largely from the warming trend; it does not predict precipitation.
New data	The summer of 2026 was the driest since 1901, with total national precipitation at 36 per cent of the normal.

The risk framework and methodology are set out in Annexes G and H. Chapters II–V deal with Hungary and the Carpathian Basin, followed by the global picture in Chapter VI. Every statement concerning Hungary is based on one of four data sources or a comparison of these. The data sources presented in Sections G.6 and H.1 are reviewed together here, as the statements in Chapters II and III are based on them.

Data source	What it says	Period	Chapter
Observation: HungaroMet homogenised daily grid, 0.1°, 1,233 grid points; cross-checked against E-OBS, the observed layer of KLIMADAT and, for 2015–2025, the CERRA reanalysis	what actually happened; all norms and trends are derived from this	1971–2025	II.1–II.6, III.3–III.4
Regional projection: FORESEE-HUN, bias-corrected EURO-CORDEX, 14-member RCP4.5 and 14-member RCP8.5 scenarios; HungaroMet KLIMADAT, four runs of two regional models under RCP4.5 and RCP8.5	what the models yield for the same indicator; to this end, we assess whether the model range covers the measurement	years overlapping with the measurement and future 30-year windows	H.2, II.1–II.4
Decadal prediction: downscaled daily grids from the National Observatory of Athens, HadGEM3-GC31-MM and NorCPM1, ten members per model	what is expected in the coming decade, where forecasting capability exists	2025–2034; forecast capability is measured using retrospective runs starting from 1980–2018	H.3, II.1–II.2
Groundwater and surface water: groundwater monitoring network: 763 wells nationwide, of which 111 are in detailed well groups across six landscape units, with a counterpart in Western Transdanubia; water level and discharge data from gauges; supplemented by satellite gravimetry	how much water is actually present in the landscape	2000–2026	III.1–III.2

In short, the rule of comparison is that the observation always takes precedence, while the projection provides the range against which the measurement is compared. Decadal predictions only play a role where retrospective verification has shown skill; in other words, this is the case for temperature (where the skill derives largely from the warming trend), but not for precipitation. Groundwater serves as an independent data source for determining whether atmospheric changes are also reflected in water resources. Where two data sources contradict each other, we do not take an average but record the discrepancy ([II.2](#)).

II.1 Heat

The observed warming in the Carpathian Basin is faster than the European average and **varies by season**: winter and summer are warm-

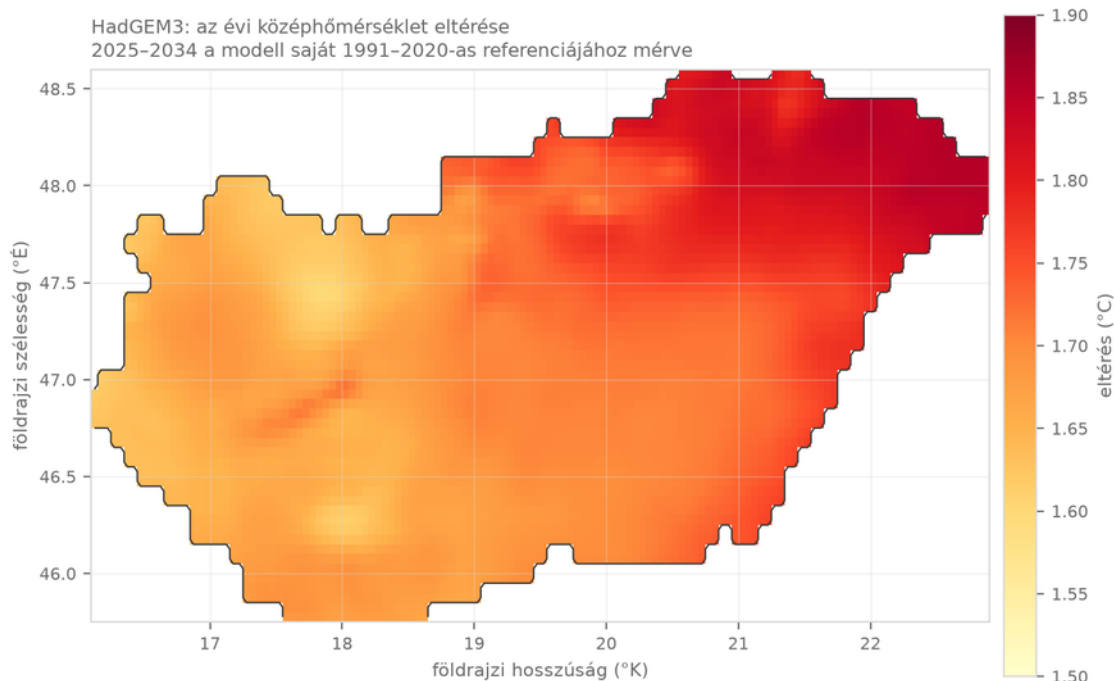
ing most rapidly, while spring is warming most slowly. The latter is significant because regional models had predicted the opposite. The slower warming in spring is one of the clearest findings of the verification, and its agricultural consequences also differ significantly from what we expected based on the models (see II.3).

Of the two model systems used for the decadal prediction, we use only the British HadGEM3; all the forecast data presented here are derived from this model. The other system, the Norwegian NorCPM1, produces a national average summer maximum temperature that is more than four degrees below the observed value. In its own reference period, it thus yields 0.05 extremely hot days per year, meaning it makes essentially no contribution to estimating changes in heat thresholds. Including such a component in the average would make the overall picture less representative of reality.⁴³ The error does not stem from downscaling; even the raw model field prior to downscaling yields a summer mean temperature nearly three degrees lower and virtually zero extremely hot days.⁴⁴

An important consequence of this is that the values reported on the basis of the decadal prediction – the annual increase of +1.3...+1.6 °C and ‘+6 extremely hot days per year in the south’ – are derived from the combined averages of the two systems. The HadGEM3 values presented here are therefore higher: **+1.7 °C for the annual mean temperature, measured against the model’s own 1991–2020 climatology, and +1.9 °C for summer in the period 2025–2034.**

MAP II/1

Annual mean temperature anomaly of the working model (HadGEM3) for 2025–2034.



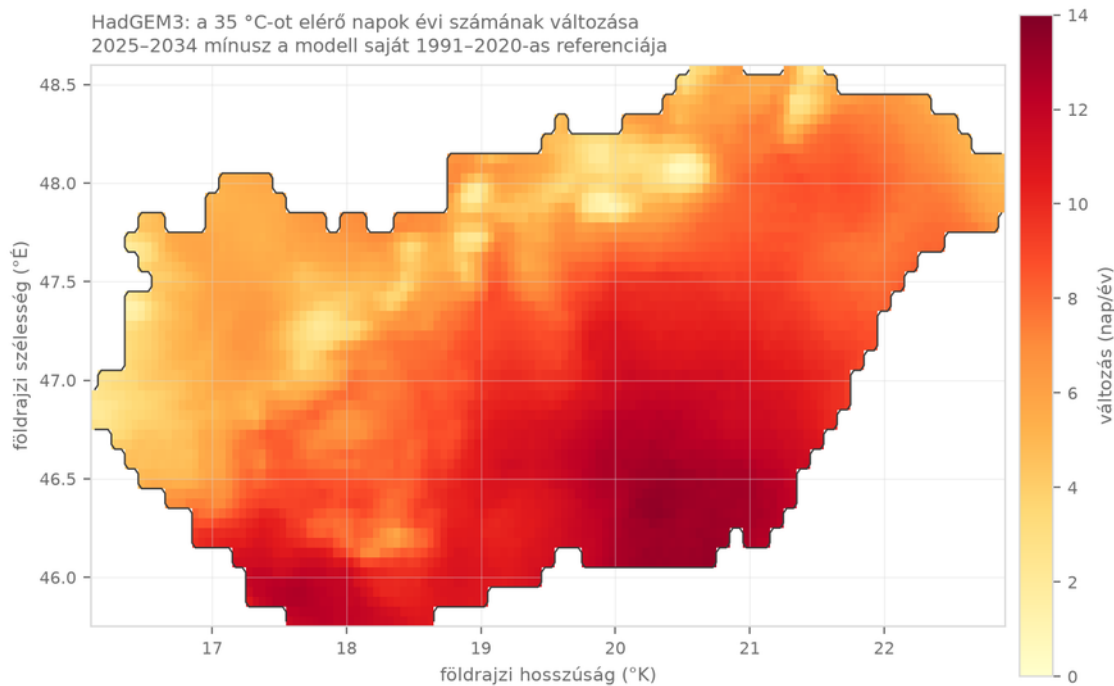
Anomaly, °C. Average of ten runs, relative to the model's own 1991–2020 reference.

SOURCE Own calculations based on the raw daily fields of the downscaled decadal prediction (dcpB-forecast, s2024 run), measured against the model's own 1991–2020 hindcast climatology. Hungary mask derived from the official 0.1° observation grid: the model is rectangular, with cells outside the country's borders omitted.

NOTE The deviation ranges from +1.6 to +1.9 °C nationwide, meaning it is almost uniform spatially: the temperature rise is not dependent on geographical region. This indicator is anomaly-linear, so the model's absolute bias is cancelled out – the map represents HadGEM3's own response, not a combination of the two models.

For extremely hot days, the signal is more pronounced, and its spatial distribution is uneven. For the number of days reaching a daily maximum of 35 °C, the model predicts an annual increase of **+8.1 days** nationwide and **+10.1 days** in the southern third of the country, with +10–12 days in its warmest runs. The temperature rise itself is almost uniform spatially, but the frequency of threshold crossings is not.

MAP II/2

Change in the number of extremely hot days in the working model (HadGEM3) for 2025–2034.

Change, days/year. Threshold: daily maximum ≥ 35 °C. Average of ten runs, relative to the model's own 1991–2020 reference period.

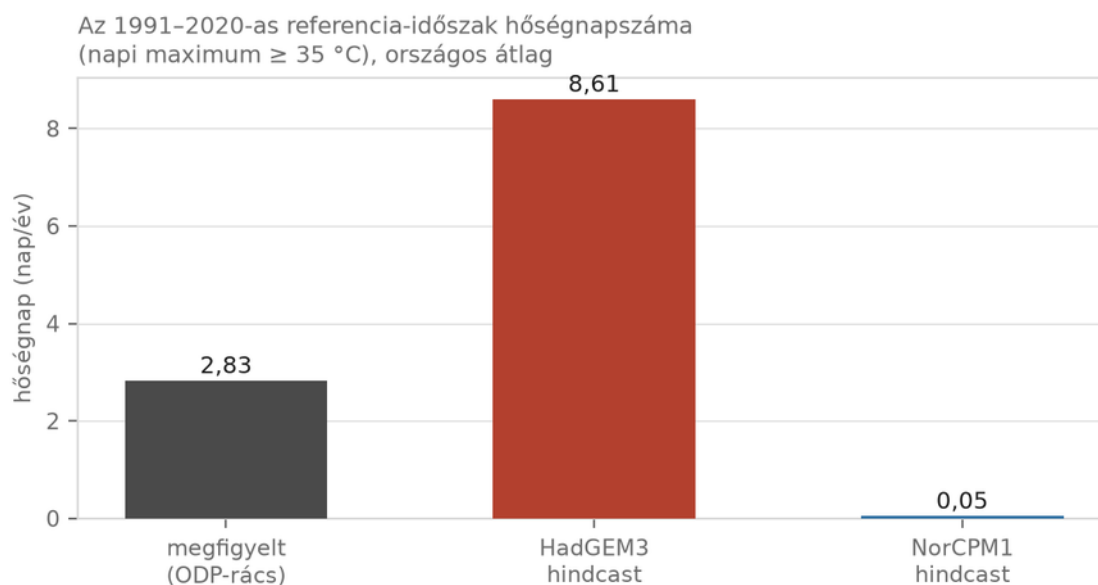
SOURCE Own calculations based on the raw daily fields of the downscaled decadal prediction (dcppB-forecast, s2024 run), relative to the model's own 1991–2020 hindcast climatology. Hungary mask derived from the official 0.1° observation grid: the model is rectangular, with cells outside the country's borders omitted.

NOTE The temperature rise is spatially uniform, but the threshold crossing is not: on the southern and south-eastern plains, the increase is two to three times that observed on the northern and western peripheries. The threshold indicator is sensitive to topography and the summer baseline, which is why the country is divided here. PLEASE NOTE: these figures are NOT planning figures – the model exceeds the number of extremely hot days observed during the reference period by a factor of three (see Figure II/3); only the direction and the spatial pattern can be adopted.

However, the fact that the model does not replicate the observed baseline situation has planning implications. On the national homogenised grid, there were 2.8 extremely hot days per year between 1991 and 2020; the model predicts 8.6 for the same period, i.e. it overestimates by a factor of three. The absolute number of extremely hot days in the projection cannot therefore be used as a planning figure; only the trend and the spatial pattern can be taken from them. The bulk of the overestimation stems from the global model; around 85 per cent of the excess is already present in the raw model output, and only around 15 per cent arises from downscaling.⁴⁴

FIGURE II/3

The number of extremely hot days in the reference period for the two models, compared with the observed data.



Days/year. Threshold: daily maximum $\geq 35^\circ\text{C}$. Period: 1991–2020, national average.

SOURCE Own calculations: observed data from the official homogenised national annual Tx series; model data from the dcppA hindcast daily fields, years 1–10 of each run, only calendar years falling within 1991–2020 (299 samples per model).

NOTE The national homogenised grid yields 2.8 extremely hot days per year. The HadGEM3 hindcast yields 8.6, while the NorCPM1 yields 0.05. One model overestimates by a factor of three, while the other underestimates by a factor of fifty. Both discrepancies are predominantly attributable to the global model, not to the downscaling (II.1). This figure explains why the absolute number of extremely hot days from either model cannot be adopted as a planning figure, and why the observed series remains the basis for scaling.

The observed series has already foreshadowed this: the national average for 2021–2025 is **8.5 extremely hot days per year**, compared with 2.8 for 1991–2020. For heat thresholds, therefore, the observed trend forms the basis for scaling, while the model projection serves as a guideline. The situation is different for the mean temperature. Here, the model value represents an anomaly, so the bias is eliminated, and the annual deviation of $+1.7^\circ\text{C}$ can be used as a design value – with the proviso that this is not a lower bound. Due to the documented historical trend bias in the working model, the value may fall towards the upper end of the possible range; however, this was not confirmed by the first observed year (H.2).

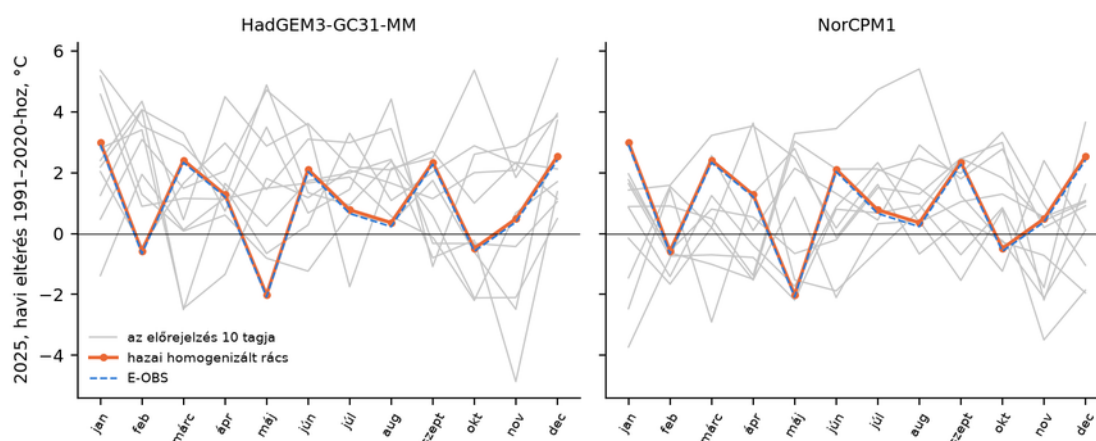
The first calendar year of the forecast, 2025, has already passed. On the national grid, the annual mean temperature was 1.0°C above the 1991–2020 average (0.9°C according to E-OBS). This value would rank fourth amongst the ten HadGEM3 members and ninth amongst the ten NorCPM1 members, counting from the coldest (Figure II/3a). Ten of the twelve months fall within the range of the HadGEM3 members, while el-

even fall within that of the NorCPM1 members. February and May were colder than the range of all HadGEM3 members, while January was warmer than the range of all NorCPM1 members. One year is not sufficient to assess the accuracy of the forecast (H.3). With regard to extremely hot days, the year 2025 shows the same bias as the reference period: there were 7.9 extremely hot days on the national grid, with every HadGEM3 member predicting more (between 8 and 37) and every NorCPM1 member predicting fewer (between 0 and 3).⁴⁵

The six-year average for 2020–2025 on the national grid exceeded the 1991–2020 level by 1.1 °C annually and by 1.3 °C in summer (E-OBS: 1.0 and 1.2 °C respectively; with 2020 also forming part of the reference period). The national grid value represents approximately two-thirds of the +1.7 °C (in summer +1.9 °C) deviation forecast by the working model for 2025–2034, and 70–86 per cent of the combined +1.3...+1.6 °C range (64–79 per cent for E-OBS). This comparison is purely descriptive (it juxtaposes the six-year observed average with the ten-year forecast average) and does not provide any indication of the rate of warming in the remaining years.

FIGURE II/3A

The first year of the forecast: the observed months of 2025 among the members of the two models.



Monthly deviation from 1991–2020, °C, based on the average of daily maximum and minimum temperatures; national average. Grey: individual members of the forecast; coloured: the two observational databases.

SOURCE Own calculations: daily fields from the downscaled decadal prediction (dcpB-forecast, November 2024 run, ten members per model), Hungary mask; HungaroMet homogenised daily grid; E-OBS v33.0e.

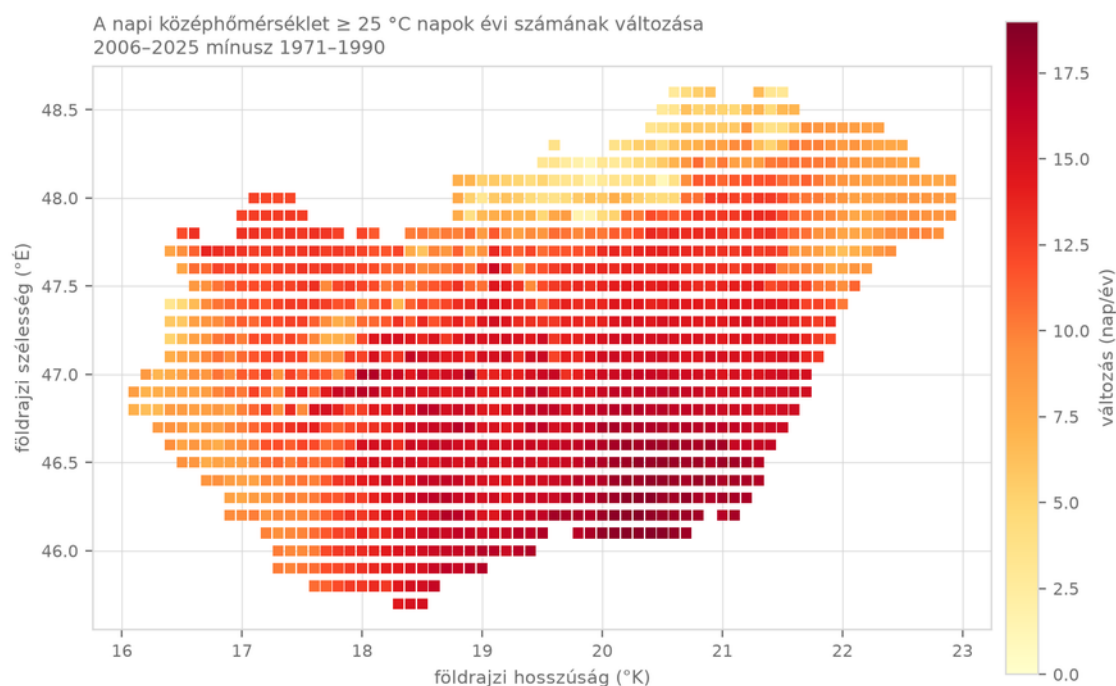
NOTE The annual value ranks fourth amongst the HadGEM3 members and ninth amongst the NorCPM1 members (1 = the coldest, 11-member series). The model-side deviation is measured against the model's own 1991–2020 climatology. A single year cannot be used to judge the forecast.

Two thresholds are of real significance (K1, K2 in the annex). From the perspective of the health burden, it is not the daily maximum that is de-

cisive, but the **daily mean temperature** – on which the national heatwave warning system is also based – as well as the number of **tropical nights**, because the absence of a night-time cool-down hinders recovery. Health and local authority planning must be guided by these two thresholds, not by record temperatures.

MAP II/4

Threshold exceedance map: spatial redistribution of exceedances of the K1 threshold.



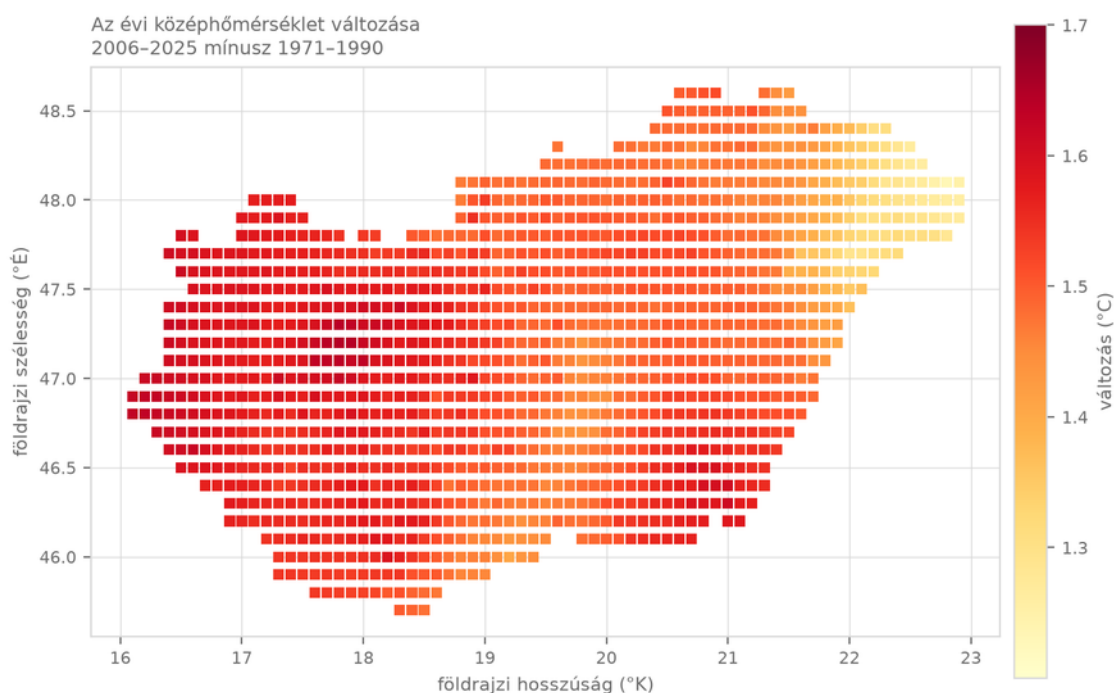
Change, days/year. Threshold: daily mean temperature $\geq 25^\circ\text{C}$. Time periods: 2006–2025 vs 1971–1990.

SOURCE Own calculations based on the official homogenised daily temperature grid.

NOTE Change in the annual number of days reaching the K1 threshold (daily mean temperature $\geq 25^\circ\text{C}$), 2006–2025 compared with the 1971–1990 period, at all 1,233 grid points. The national median is +12.9 days/year, with a range of +1.0 to +18.7 days. The increase is positive everywhere, but is two to three times greater in the flat, south-eastern areas than on the western and northern peripheries – the heat burden is therefore uneven across the country, and planning must take this into account.

MAP II/5

Change in annual mean temperature between the same two periods: median +1.51 °C, range +1.23 to +1.64 °C.



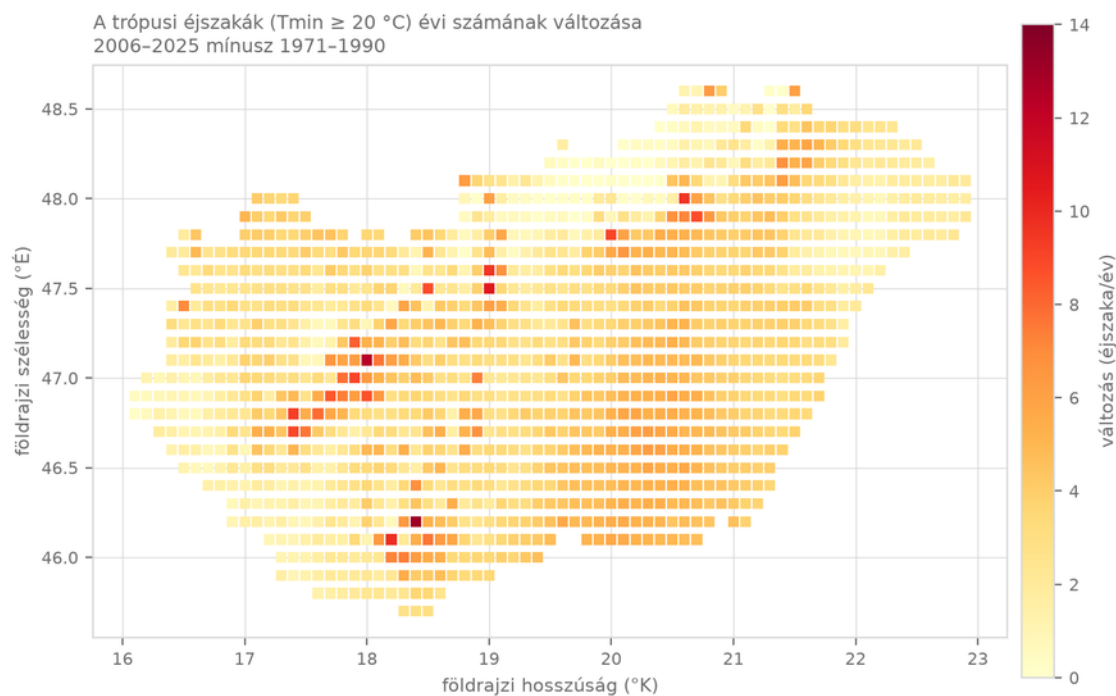
Change, °C. Time periods: 2006–2025 vs 1971–1990.

SOURCE Own calculations based on the official homogenised daily temperature grid.

NOTE This measure is much more spatially uniform than the number of threshold days – and this difference is the crux of the risk analysis, as the average rises uniformly, whereas the number of threshold exceedances does not. A uniform warming of 1.5 °C means eighteen additional days exceeding the threshold in some places, and just one in others.

According to a breakpoint analysis, the temperature series do not rise uniformly but instead **shift to a new level**: the annual mean temperature has been 1.3 °C higher since 2005, while the summer mean temperature has been 1.8 °C higher since 1991. Decadal averages show the same trend – the annual mean has risen from 9.9 °C (1971–1980) to 12.0 °C (2021–2025), and the summer mean from 19.1 °C to 22.4 °C. The implications for planning are twofold: systems designed based on the average of the long-term data series are calibrated for a **past climate regime**, and the most recent, partial decade is the warmest on both series. Over the same two time periods, the global mean surface temperature rose by 1.0 °C (Had-CRUT5, own calculations)⁴⁶, meaning that the shift in Hungary is greater than the global one. This ratio applies only to this specific pair of time periods and is not constant; therefore, it does not provide a multiplier for converting the global trend to the Hungarian one (VI.6).

MAP II/6

Change in the annual number of tropical nights ($T_{min} \geq 20^\circ\text{C}$).

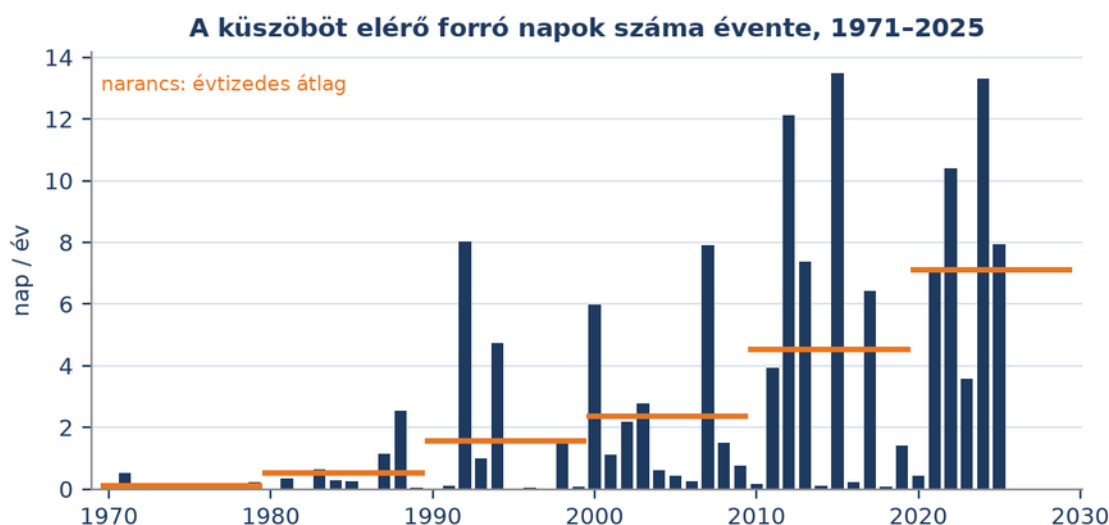
Change, nights/year. Time periods: 2006–2025 vs 1971–1990.

SOURCE Own calculations based on the official homogenised daily temperature grid.

NOTE The national median is +3.3 nights, but the maximum is +13.1 – and the pattern here is the most uneven of all the indicators examined. This figure is more significant in terms of health risks than the daytime peak: the absence of a night-time cool-down hinders the body's recovery. The areas most affected are densely populated, lowland urban areas – in other words, exposure and hazard coincide spatially here.

FIGURE II/7

Threshold crossing diagram: annual number of extremely hot days as a national grid average.



Days/year. Threshold: daily maximum temperature $\geq 35^\circ\text{C}$. National grid average, 1971–2025; orange line: decadal average.

SOURCE Own calculations based on the official homogenised national annual Tx series (grid average).

NOTE This figure uses a DIFFERENT THRESHOLD to Map II/4: there, the threshold is the daily mean temperature $\geq 25^\circ\text{C}$; here, it is the daily maximum $\geq 35^\circ\text{C}$. Both were calculated per grid point; there they are shown as a map, here as a national average. The two quantities differ; their values cannot be compared, and neither can be interpreted as a spatial or temporal projection of the other. This series is the source of the 2.8, 4.9 and 8.5-day values in II.1 and VIII.1 and of the observed extremely-hot-day values in the table of Note 231. The figure of 17.4 days, which appears elsewhere, is the aggregated value for 266 stations in 2026, while 19.3 refers to the number of VPD threshold days – neither of these belongs to this row.

METHODOLOGICAL DETAIL

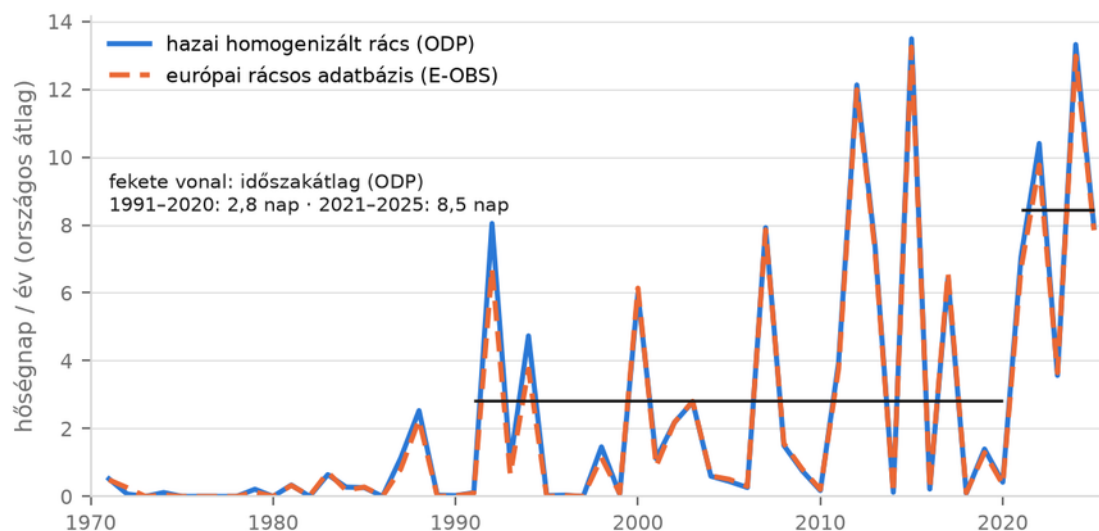
The number of extremely hot days is also reported by a second, European database. The E-OBS database, which is derived from station data provided by European meteorological services and interpolated onto a grid, uses a different interpolation method and a sparser domestic station network than the domestic homogenised grid. Nevertheless, for the same two periods, it gives annual figures of 2.7 and 8.2 extremely hot days, compared with the domestic figures of 2.8 and 8.5. The two annual series are almost identical between 1971 and 2025 (Figure II/7a).⁴⁷ This agreement confirms the robustness of the processing, but it is not confirmation by an independent measurement network, as the two databases are partly based on the same domestic measurements.

The two databases differ in the absolute number of tropical nights. E-OBS gives an annual average of 2.6 nights for the 1991–2020 period, compared with 1.9 for the domestic grid, and generally shows warmer night-time minimum temperatures. The increase for 2021–2025, however, is around four and a half nights in both. Planning should therefore be based, for the K2 (tropical night) threshold, not on the database-dependent absolute level, but on the magnitude of the change – the increase of approximately +4.5 nights for 2021–2025 compared to the thirty-year average –

which is consistently reported by both databases. This figure represents the difference between period averages, not a trend estimate.

FIGURE II/7A

The annual number of extremely hot days is almost identical in two grid-based databases produced using different methods.



Days/year, the national average of the number of extremely hot days (daily maximum $\geq 35^\circ\text{C}$) calculated per grid point, 1971–2025; black line: the period average for the Hungarian grid.

SOURCE Own calculations: HungaroMet homogenised daily grid (1,233 points) and E-OBS v33.0e (0.25°), fitted to the national grid points.

NOTE The correlation between the annual series of the two databases is 0.998. As in Figure II/7, the threshold was applied at each grid point and the counts were averaged (Annex B).

METHODOLOGICAL DETAIL

An atmospheric reanalysis could provide an independent comparison; therefore, we also examined the 2015–2025 period using the European regional reanalysis (CERRA, 5.5 km).⁴⁸ The reanalysis integrates the measurements into a physically consistent field generated by a weather forecasting model; it does not interpolate station data. It matches the national grid well in terms of level: the deviation in annual mean temperature remains between -0.30 and $+0.18^\circ\text{C}$.

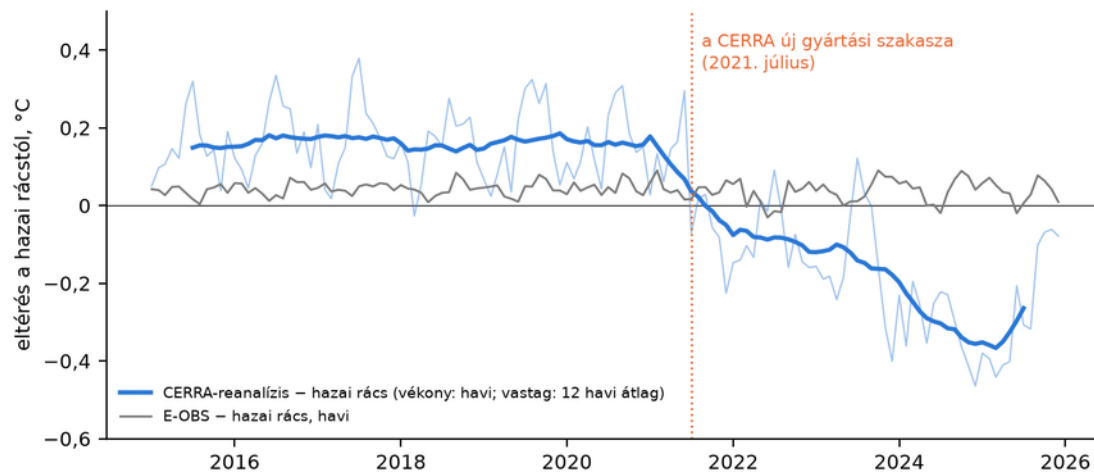
However, it cannot be used to assess trends. The discrepancy between the two datasets shifts by approximately a quarter of a degree in July 2021, at the start of a new production phase for the reanalysis, and then shifts by a further quarter of a degree by 2025, while the discrepancy between E-OBS and the national grid remains constant throughout (Figure II/7b). Consequently, the reanalysis shows a warming of only 0.06°C between 2015–2019 and 2020–2025, compared with 0.32°C for the domestic grid. The cause is unproven; due to the shared station base, a change on the domestic side cannot be entirely ruled out, but the coincidence of the 2021 date with the production change points towards the reanalysis side. The reference period (1991–2020) for downscaling the decadal prediction falls within the period prior to the change and is therefore unaffected by it.

From a planning perspective, the consequence of these two checks (see the methodological details) is that the domestic warming observed in the 2020s is currently shown by two observational databases that are not in-

dependent of one another – in essence, a single network of stations. This does not refute the measured signal, but independent confirmation is as yet lacking.

FIGURE II/7B

The discrepancy between the reanalysis and the domestic grid shifts in mid-2021, whereas that of the E-OBS does not.



Deviation from the national daily mean temperature of the Hungarian homogenised grid, °C, 2015–2025; blue: CERRA reanalysis (thin line: monthly; thick line: 12-month centred moving average, which smooths out the jump; the break is visible on the monthly line); grey: E-OBS.

SOURCE Own calculations: CERRA reanalysis, 2 m temperature (Copernicus Climate Change Service); HungaroMet homogenised daily grid; E-OBS v33.0e; the reanalysis cell closest to the domestic grid point.

NOTE The daily mean of the reanalysis is the average of the eight daily analysis times. The July 2021 boundary is provided by the service provider's production documentation; it was not selected from the data; the analysis of the shift is retrospective and descriptive.

II.2 Drought – and what has not increased by 2025: the duration of dry spells

The risk of drought is not increasing where we expect it to – that is what this section is about. In Hungarian public discourse, the image of drought is that of weeks on end of cloudless skies and cracked stubble fields. In the measurements, this image is represented by the length of the longest continuous period without precipitation – the number of consecutive days without rain. This indicator does not increase between 1971 and 2025. The trend shows a slight downward slope, and its uncertainty band comfortably encompasses zero.

The statement is valid subject to two qualifications; without them, it implies more than it should. (1) The nature of the indicator: the rain-free period does not measure drought, but rather *the continuity of the absence of rainfall*. Consider a summer in which two millimetres of rain falls every three weeks. According to the indicator, there is no long dry spell

in this scenario, because every small amount of rain ‘interrupts’ the sequence – yet for the soil and plants, those two millimetres contribute nothing, as they evaporate within a few hours. Such a summer is, in agricultural and hydrological terms, a drought throughout, yet the indicator of the length of the dry spell does not reflect this.

(2) End of the data series: the series ends in 2025 because the homogenised datasets – those gridded databases in which measurement errors and station relocations have already been corrected – are only finalised some time after the measurements have been taken. **2026 is therefore not included in the trends shown in the table, even though it brought precisely the sort of summer that common expectations would suggest.** We examine that year separately, using a station-level data series, at the end of the chapter.

The planning conclusion is therefore not that there will be no prolonged droughts, but rather that the duration of dry periods is not the indicator by which an increase in risk can be demonstrated. It is a mistake to base assessments solely on its trend. The measurable increase lies elsewhere – in evaporation rates and in the intensity of precipitation.

Results, on the official homogenised grid, 1971–2025:⁴⁹

Indicator	1991–2020 normal	trend, 1971–2025 (95% CI)	p
Longest dry spell, annual	27.4 days	–0.43 [–1.35; +0.49] days/ decade	0.364
the same for the growing season (April–September)	18.8 days	–0.01 [–0.61; +0.58]	0.962
total summer rainfall	203 mm	–3.2 [–12.4; +6.1] mm/ decade	0.504
annual precipitation	616 mm	+7.0 [–10.6; +24.6] mm/ decade	0.437
number of dry days in summer	66.5 / 92 days	+0.80 [+0.07; +1.53] days per decade	0.037

The table should be interpreted in conjunction with two rules of interpretation.

The first relates to the threshold. ‘Dry day’ here means that daily precipitation does not reach 1.0 millimetres – this is the convention used in the international climate index set. This choice is significant because, with a threshold of 0.1 millimetres, the same normal would be 19.0 days instead of 27.4 days; therefore, such a value can only be quoted in conjunction with the threshold.

The second point concerns what appears to be an outlier in the table. The trend in summer dry days (+0.80 days/decade, $p = 0.037$) seems, at first glance, to be the only genuine signal in the table, but it is not. When running many trend tests on the same data set, one of them is bound to cross the threshold purely by chance; therefore, the threshold must be adjusted according to the number of tests. The corrected threshold is roughly 0.0005 (G.6, Annex B, point 7); 0.037 is far from this. It may be cited as an indication of direction, together with its p -value, but not with the label ‘significant’. However, a strict threshold can easily fail to detect a genuine but weak signal (the second type of error described in G.5), so it is the confidence interval—not the threshold—that indicates that the dry period has not increased. The 95 per cent range of the annual trend lies between -1.35 and $+0.49$ days per decade (with the t -distribution, the upper limit is $+0.51$); therefore, an increase of more than about half a day per decade can be ruled out with 95 per cent confidence. The data do not rule out an increase smaller than this.

A 2025 Hungarian study, using an independent database, a different threshold (3 mm) and a different seasonal window (July–September), reaches the same conclusion: the national average for the longest dry spell decreased slightly between the two sub-periods examined, from 23 to 21 days.⁵⁰ At the same time, the standard deviation of spatial maxima increases by around three days. In other words, it is not the whole country that is drying out evenly, but rather the worst-affected regions are faring increasingly worse relative to the average. From a planning perspective, this is not reassuring; it merely points in a different direction.

METHODOLOGICAL DETAIL

To verify our own calculations, we use the observed layer of HungaroMet’s KLIMADAT service, which reports the same indicator using the same convention. Across five overlapping 30-year windows, our series—constructed from our own raw daily grids—reproduces the official value to the nearest hundredth: for 1971–2000, we give 29.07 instead of 29.08, and for 1991–2020, 27.36 instead of 27.37. This match indicates that the result is not an artefact of our method.

In the sixth and most recent time window (1996–2025), however, the value is 0.45 days higher. The most likely cause is year-to-year differences in the last one or two years; however, this cannot be determined with certainty because the official service does not publish annual layers.^{51,52}

The KLIMADAT projection layer indicates a reduction of approximately four days in the annual longest dry period from the 2001–2030 window onwards, compared with the 1971–2000 level (median of 3.8–4.6 days for the 2011–2040 and 2026–2055 periods). This value remains virtually unchanged until the end of the century. In the same service, the measured value decreased by 2.1 days between 1971–2000 and 1996–2025, meaning

it lies above the range of the four runs, on the drier side. Neither result can be interpreted as a climatic signal. The service adjusts precipitation to the observations using a monthly ratio, which corrects the monthly total but not the number of rainy days. In the four runs, the number of rainy days in the 2001–2030 period is already around 27 days higher than the measured value, and more frequent light rainfall interrupts dry spells (H.2). In our assessment, the projection layer therefore does not provide conclusive evidence regarding the trend in the length of dry spells. In the bias-corrected FORESEE-HUN, the number of days with precipitation is close to the observed value, and the range of the 28 runs covers the observed value. This is therefore the indicator where the minimum rule – the rule explained in section H.2, according to which the lower end of the model range is not a conservative estimate but a lower bound – does not apply. This holds true for the average; the extreme value for 2026 is discussed at the end of the chapter.

The decadal prediction product,⁵³ by contrast, indicates a +0.70-day increase in the dry period for Hungary, meaning a lengthening of the dry period by the mid-2025–2034 decade. Four comments are necessary to interpret this discrepancy.

- The uncertainty range encompasses zero and is wider than the signal itself: between –2.35 and +3.53 days.
- The projection horizon and reference period do not correspond to those of the domestic projection sets; therefore, the values are not directly comparable.
- The decadal prediction has a low proven accuracy for precipitation – this tool estimates temperature trends well, but essentially does not estimate precipitation amounts.
- No accuracy values are available for the Carpathian Basin for any of the products.

The conclusion is therefore not that ‘the sources contradict each other, so we know nothing’. Two mutually independent, observation-based calculations indicate that the average is not increasing, and the FORESEE-HUN range is consistent with this. In contrast, a low-skill, wide-range product suggests an increase, with a range that includes zero. The official projection does not settle this issue. The weight given to the two sides is therefore not equal.

The extremes of the distribution are another matter. The cited domestic study⁵⁰ – in its projection section, based on the average of six regional

model simulations — often shows no significant change in the average duration of the longest dry period (with a 3 mm threshold) between July and September, except towards the end of the century under the high-emissions scenario; however, the tail of the distribution shifts towards longer periods. Periods of at least 40 days occurred across 32 per cent of the country between 2004 and 2023, 2–5 times in a 20-year period; the article reports figures of 39 per cent, 58 per cent and 80 per cent for the three future time periods (2041–2060, 2061–2080, 2081–2100). The publication does not specify a scenario; the high-emission scenario is inferred from the context. This does not provide a strong indication for the 2026–2035 horizon, but the statement ‘does not increase’ applies to the mean, not to the extremes of the distribution.

The validity limits of this result are illustrated by the counter-example of last summer. In the summer of 2026, a prolonged blocking anticyclone sat over the Carpathian Basin: a high-pressure system that stalls weather systems arriving from the west for weeks, and while it persists, neither fronts nor rain can penetrate beneath it. The heat and drought persisted simultaneously for weeks – precisely the weather situation that is missing from the data set above.

According to HungaroMet’s summer assessment of 7 September 2026, the national total rainfall for the summer was **74.1 mm**, 36 per cent of the 1991–2020 normal of 203.3 mm: **the driest summer since 1901**, 27.2 mm below the previous record of 101.3 mm set in 1952. The same summer was the second hottest since 1901, with a national average temperature of 23.43 °C, 2.59 °C above the normal. According to a statement by the data provider quoted in the press, 98 per cent of the country’s territory experienced moderate or more severe agricultural drought, and 47.1 per cent experienced the most severe level of agricultural drought.⁵⁴

We also calculated the duration of the dry period for this year at the ten stations in the homogenised series that have been recording data since 1901, using the data provider’s daily station data for 2026 and the same 1.0 mm threshold.⁵⁵ During the growing season, between April and September, the average longest dry spell across the ten stations was 30.2 days: **the longest since 1901**. This exceeds the 1991–2020 average of 20.2 days by more than two standard deviations, but is only 1.2 days longer than the previous record (1992: 29.0 days). In the summer period (June–August), it ranks second at 25.7 days, behind 1992. Counting from the start of the calendar year, however, it ranks only fourteenth, as the annual maximum is often set during the dry periods of winter and early

spring. Consequently, the record does not appear in the annual figure, and this is probably why the annual figure says little about the summer either (we infer this; we have not examined it specifically). The picture varies geographically: in Szeged, 53 days (the previous record was 41 days); in Debrecen, it is tied for second place; in Nyíregyháza, third; in Miskolc, tied for fifth to seventh place for the longest duration since records began; while in Sopron, Szombathely and Keszthely, the figure is average. The record was not preceded by a build-up: the average for the 2016–2025 decade is 19.2 days, which is below normal.

This is a single-year occurrence and **does not contradict** the trend observed over the fifty-five-year series: a record summer involving a block can occur even if the distribution of the dry period does not shift. In a long series, the record will eventually be broken even with an unchanged distribution. A single year is not enough to determine whether we are seeing an extreme outlier or a turning point. Section VIII.8 specifies what kind of observation would determine this. At the same time, it offers three lessons.

(1) It shows that a long, continuous drought is a physically possible scenario in today's climate – not a risk for the future, but one for the present. It also shows that a trend is not the same as an extreme event: anyone who interprets the trend in the length of dry spells to mean that there is no need to prepare for long droughts will find themselves at odds with the summer of 2026. (2) Section II.5 adds the other half to this: the literature is divided on the future frequency of blockage events, so we must take today's frequency as our starting point, and preparations must be scaled to cope with at least this. (3) The scaling is based not on the trend, but on the design event, and 2026 has shifted that event. The design event for reservoir and irrigation development is the longest dry spell during the growing season measured in the given region in 2026 (an average of 30.2 days across the ten stations, 53 days in Szeged), whether this proves to be a spike or a turning point. This proposal is based on the 2026 measurements.

The evaporation side: the strongest observed signal

So far, we have discussed how much water arrives; from here on, we will look at how much the air carries away. The vapour pressure deficit (VPD) measures how much more water vapour could fit into the air beyond what is currently present. This quantity is important because the rate of evaporation depends not only on temperature but also on this difference; thus, the same 30-degree day imposes a different evaporation load on the

landscape depending on how saturated the air is. In humid conditions, the deficit is low and evaporation is slow, because the vapour ‘has nowhere to go’. In dry air, the deficit is high and evaporation is rapid, provided there is something to evaporate – from the soil, the vegetation and open water surfaces alike. On parched soil, actual evaporation no longer keeps pace with the increase in the vapour pressure deficit; at this point, the plants suffer from water deficiency. The unit of measurement is the pascal.

The following statements are based on the strongest statistical signal in the entire analysis. The vapour pressure deficit has been rising across four indicators over a period of fifty-five years, and all four tests within the long window exceed even the most stringent multiple-test threshold calculated for the project as a whole – that is, the threshold which the trend in dry summer days failed to reach earlier.⁵⁶

indicator	trend, 1971–2025 (95% CI)	1971–1980	2021–2025
annual VPD	+32.2 Pa/decade [+23.9; +40.6]	644.5 Pa	823.9 Pa
summer (JJA) VPD	+73.2 Pa/decade [+53.6; +92.8]	1113.7 Pa	1545.4 Pa
Days with ≥ 1500 Pa	+6.91 days per decade [+5.12; +8.70]	18.7 days	56.9 days
Days with ≥ 2000 Pa	+2.91 days per decade [+1.91; +3.90]	0.9 days	19.3 days

In relative terms, the annual vapour pressure deficit has increased by +28 per cent since 1971, and by +39 per cent in summer. These are VPD values, not calculated evaporative demand (ET₀; see the methodological details). The bottom two rows of the table are the most striking: the number of days with persistently high vapour pressure deficits has tripled, while the number of the most extreme days has jumped from a single day per year in the 1970s to around twenty per year.

METHODOLOGICAL DETAIL

We carried out three checks to verify whether this signal is genuine:

(1) Data source. The above series is derived from a method that estimates air humidity from the daily minimum temperature – this is a well-established approximation. On the actually measured air humidity grid, the same trend is +26.5 Pa per decade [+18.3; +34.7]; that is, the level is lower, but the direction and order of magnitude are the same, so the signal does not originate from the approximation.

(2) Mechanism. If the rise in the vapour pressure deficit is genuine, then there must also be evidence of it in the temperature series. This is because, over dry soil, a smaller proportion of incoming solar energy is converted into evaporation, while a larger proportion is used to heat the air; con-

sequently, days warm up faster than nights – the diurnal temperature range widens. In the measured data, the annual temperature range has increased from 9.64 °C in 1971–1980 to 10.85 °C in 2021–2025, and the summer range from 11.74 to 13.79. However, the diurnal temperature range and the vapour pressure deficit are two aspects of the same physical phenomenon, not two independent pieces of evidence; therefore, adding them together would amount to double-counting.

(3) Comparison of the calculated evaporative demand and the vapour pressure deficit. The vapour pressure deficit measures the air's capacity to hold water, not the amount of water that has evaporated. The reference evaporative demand (ET₀) according to the FAO-56 standard rose by +5.8 per cent, and by +8.4 per cent in summer, on the same grid between 2001–2010 and 2016–2025 – at a significantly slower rate than the vapour pressure deficit. The two are not interchangeable, and a proportional increase in evaporation cannot be inferred from the increase in the vapour pressure deficit.

The vapour pressure deficit is not the same as water lost through evaporation: according to measurements from the Hungarian University of Agricultural and Life Sciences (MATE)'s Bugac eddy covariance station – which are due to be published – actual evaporation has not kept pace with the increase in evaporative demand for some time now. Potential evaporation therefore says little about actual water turnover (Zoltán Nagy and Krisztina Pintér, MATE, personal communication, October 2026). According to measurements from the same source for the period 2003–2017, during drought-stricken summers evaporation even exceeded summer precipitation; the difference was covered by stored water reserves.²¹¹ According to national estimates calculated on the basis of the complementary principle, actual evaporation increased by 1.6 mm per year between 1981 and 2020, a slower rate than that of reference evaporation (2.2 mm per year).²¹² Between 2000 and 2022, it increased less than precipitation at the national level, while it decreased in the Great Plain and the northern part of the Danube–Tisza region.²¹³ However, according to a yet-to-be-peer-reviewed water balance estimate for the Danube–Tisza region covering 1950–2024, the recharge resulting from the difference between precipitation and evaporation fell from around 130 mm in the early 1950s to 14 mm by 2024.²¹⁴ These two pictures are compatible. Where there is water in the soil – in spring and autumn, in forests and above shallow groundwater – actual evaporation also increases as temperatures rise. Where there is no water – on parched sandy grassland in summer – only the evaporation potential increases; actual evaporation does not follow suit. This is our own interpretation, which still needs to be corroborated by seasonal domestic measurements. Figures II/9 and II/10 also show the vapour pressure deficit, not the calculated evaporation potential.

The literature is not unanimous regarding the driving forces behind drought. In the Great Plain, the observed drought index was somewhat

more closely correlated with summer precipitation than with summer temperature; however, this difference stems mainly from the index formula.²¹⁵ An attribution study attributes the increasing frequency of summer soil moisture droughts in Western and Central Europe, similar to that of 2022, probably to regional warming, while finding no clear trend in precipitation; in the 2022 event itself, a lack of precipitation also played a role, primarily as a result of natural variability.²¹⁶ In the western United States²¹⁸ and in Central and Southern Europe²¹⁹ alike, an increase in evaporative demand was identified as a significant driver of drought. The two sets of data on the transitional seasons in Hungary do not point in the same direction. Relative humidity decreased significantly at all stations studied between 1961 and 2020 in spring and summer; there is no clear trend in autumn and winter.²²⁰ The Thornthwaite water balance shows a surplus in spring and a deficit in autumn, but since 1971 there has been no trend in either season, neither in the national average nor in the Lake Balaton catchment area (Péter Szabó, own calculations, personal communication, October 2026).

The projection does not reflect the increase in the vapour pressure deficit

A regional model ensemble is not a single model run, but rather several parallel runs – referred to in the field as ‘members’ – which calculate the same future scenario from slightly different initial conditions. The mean of the model ensemble is the average of the runs, while the standard deviation of the members indicates the degree of uncertainty acknowledged by the model itself.

The available model ensemble projects a trend in annual VPD of +0.8 Pa per decade for the thirty-year period 2025–2054 under the moderate emissions scenario and +8.6 under the high emissions scenario, compared with the observed value of +32.2. The model ensemble therefore effectively does not project an increase in vapour pressure deficit.

It fails to reproduce not only the magnitude but also the mechanism – the daily temperature fluctuation expanding over dry soil. It narrows the temperature fluctuation (ensemble-member mean $-0.085 \dots -0.123$ °C/decade), while the observations show an expansion. At the centre of the model ensemble, the discrepancy is therefore not in magnitude but in sign.

At the member level, the statement regarding the sign does not hold, as in each case one of the twenty-eight members reaches the observed

trend (+28.5 and +36.6 Pa per decade, respectively). The model could therefore predict such a future, but this is not the most likely outcome.

However, for the four VPD indicators, not even the most extreme member reaches the value already measured:

indicator	the model's most extreme member	the observed value for 2021–2025
Annual VPD	815.9 Pa	823.9 Pa
summer VPD	1516.0 Pa	1545.4 Pa
Days with ≥ 1500 Pa	54.9 days	56.9 days
Days with ≥ 2000 Pa	17.0 days	19.3 days

A lack of coverage – that is, the fact that the entire range of the model falls below the observed value – is not the first time this has occurred in the analysis (Section H.2 lists four such indicators), but here it is the most rigorous comparison, because we are comparing not two different data sources, but the same model's own extreme member with the measurement (Figure II/10a).

This does not imply that the future will certainly be worse, but rather that we currently have no usable projections for this variable, and planning must rely on the observed trend rather than on the models.

The vapour pressure deficit for the 28 runs is not derived from the regional models' own humidity data. The projection database calculates it from the bias-corrected daily minimum and maximum temperatures and precipitation, using the same minimum-temperature-based estimation on which the primary data set of the observed series is also based. Air humidity is not affected by the bias correction.⁵⁶ The two sets were therefore produced using the same procedure; consequently, the majority of the discrepancy between the model and the measurements stems from the temperature and precipitation patterns of the models, such as the narrowing of the temperature range. The trend calculated from the measured air humidity grid is also several times greater than the projected one. However, the estimate itself loses part of the signal, because the actual water vapour content of the air does not follow the night-time minimum temperature; thus, when calculated on the same basis as the measured air humidity, it reflects only about two-thirds of the summer rise. The loss is greatest during heatwaves of over 30 °C lasting at least three days above dry soil. During such periods, the measured water vapour content of the air has not risen over the past fifty-five years, and the estimate captures only about half of the observed increase in the vapour

pressure deficit. The number of such days has more than tripled compared with the 1970s, with the summer of 2022 recording the highest number in the measurement series. On the critical days of the summer of 2026, the difference between the measured and estimated vapour pressure deficit was greater than ever before. The observed atmospheric drying is therefore even more pronounced than the figures above suggest. It remains an open question whether the regional models’ own calculations of atmospheric humidity would reproduce the observed drying – to do so, the vapour pressure deficit would need to be recalculated from the models’ humidity data, corrected against the measured reference (IX.11).

To date, the analysis has identified only one mechanism underlying this discrepancy: aerosol clearing (VI.2). A 2026 study adds a second reason: the models are known not to reproduce the observed changes in European atmospheric circulation, while 42 per cent of the observed increase in the vapour pressure deficit is circulation-driven.⁵⁷ **These two causes are not independent of one another and cannot be cited as mutually reinforcing evidence.** The study itself states that the decline in cyclonic activity in south-eastern Europe may partly reflect the reduction in aerosols and rising carbon dioxide levels. Further limitations of the study are that the decomposition into components was carried out using a single model, the method excludes the influence of thermodynamics on the flow, and the study area covers the mid-latitudes of Europe rather than the domestic territory; thus, in accordance with Rule VI.6, it must be regarded as context and boundary conditions. The 10-centimetre soil moisture variable in the study cannot be linked to the groundwater layer described in Chapter III of the analysis.

The five values cited in the executive summary from this study are as follows. The study divides drying into two parts: the direct (thermodynamic) effect of warming and the (dynamic) effect of changes in atmospheric circulation.

Quantity	thermodynamic component	flow-dependent component	comment
trend in the vapour pressure deficit	58 %	42 %	42 per cent is the reported value; 58 per cent is the complementary value
the decrease in modelled soil moisture, averaged across the region	45 %	55 %	55 per cent is the reported value; 45 per cent is the analysis’s own calculation
The trend in precipitation	the decrease is offset by 6 per cent	–	the thermodynamic term is not neutral here

Quantity	thermodynamic component	flow-dependent component	comment
the modelled decrease in soil moisture, regionally (Western and Eastern Europe)	–	up to 80 per cent	maximum value

The figures are sourced from Dunkl, Bastos and Sippel (2026), *Nature Geoscience*. The analysis was carried out using a single model (CESM2), covering summers from 1980 to 2024 in the mid-latitudes of Europe, and the soil moisture values are modelled quantities, not measurements.⁵⁷

The precipitation side: the same amount of water, but on fewer occasions

A 2025 Hungarian modelling study, based on adjusted data, concludes that annual precipitation **will increase** – by up to 30 per cent in mountainous areas – while the number of days with precipitation will decrease by 1–7 days, and daily maximum rainfall will rise most sharply in summer.⁵⁸ The same amount or more water will therefore fall, but on fewer occasions and with greater intensity. From the perspective of soil and water resources, this is likely to mean less usable precipitation, as a larger proportion of short, intense rainfall may run off before it can infiltrate. This is an inference; there are no domestic measurements of the proportion of intense rainfall that infiltrates (III.4).

The observations paint the same picture. Precipitation in the summers of 2022, 2024 and 2025 was 68 per cent, 65 per cent and 60 per cent of the normal, respectively, while the five-year average for 2021–2025 was 150 mm, **or 74 per cent of the normal**. At the same time, the uncertainty interval for the fifty-five-year trend in summer rainfall comfortably encompasses zero (p = 0.50). The two statements are compatible, as the last five years have been exceptionally dry; however, five years are not statistically sufficient to confirm a decade-long trend. The first statement is, on its own, an exaggeration; the second, on its own, overlooks the last five years.

The international literature points in the same direction. Observed air humidity over arid regions has not increased for four decades, while virtually all global model runs predict an increase. Furthermore, the nature of European droughts has changed, with short, warm-season, evaporation-driven events becoming the norm.⁵⁹ This is not an independent confirmation of the domestic findings – a different region, different data – but rather an indication that the models are underestimating atmospheric drying elsewhere as well. The domestic discrepancy, however, does not

prove the same error, because the domestic database does not calculate the vapour pressure deficit from the models' atmospheric humidity.

Two further studies, from 2024 and 2021, also separately confirm the findings regarding evaporative demand. A 45-site tree-ring isotope network reconstructs the summer vapour pressure deficit over four hundred years and concludes that today's atmospheric drying is unprecedented in the pre-industrial context, placing the probability of human influence at over 98 per cent. **One of the four formally attributed regions is the Central and Eastern European cluster, i.e. the region of Hungary.**⁶⁰ This, in terms of the data on which this chapter is based, rules out the interpretation that 'it falls within the range of natural variability'. An analysis covering the period from 1902 to 2019, based on three drought indices, reveals the same pattern on a continental scale: Central Europe and the Mediterranean are becoming drier, while Northern Europe is becoming wetter, and the driving force is increasing evaporative demand and mean temperature, not precipitation. The drying trend is indicated by the two evaporation-sensitive indices, but not by the precipitation-only index.⁶¹ However, the evaporative demand calculation in the study uses air humidity as an input, just as the vapour pressure deficit layer discussed in this chapter does; thus, it constitutes methodologically related, rather than independent, evidence. This does not affect the analysis's own argument, which is based on the measured vapour pressure deficit.

The cost of the two kinds of error on the two indicators

The cost of error differs for the two indicators discussed in this chapter.

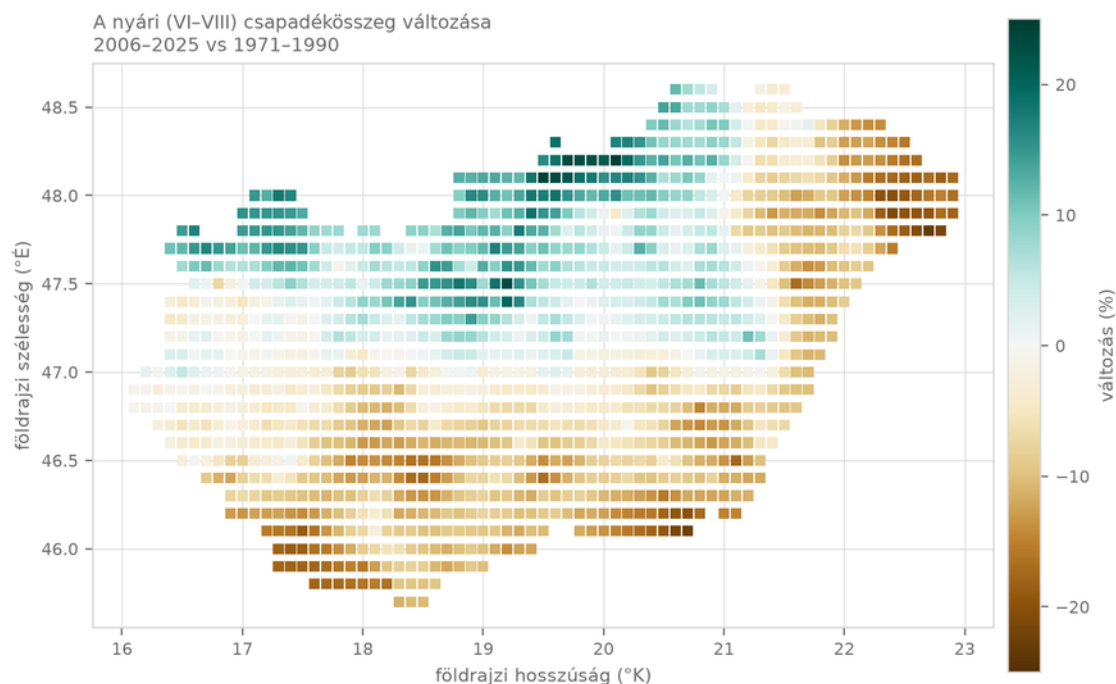
As regards the duration of dry spells, the trend does not justify an upward correction, as both the data up to 2025 and the FORESEE-HUN range show that the signal is not where we would expect it to be. Sizing, however, is based not on the trend but on the design event, and this was shifted by the 2026 record. The cost of error is asymmetrical here too, because a reservoir sized for a longer dry spell also protects against increasing evaporation losses; therefore, only the smaller part of any oversizing is wasted expenditure, while undersizing, on the other hand, locks us in for decades – this is our assessment.

For the vapour pressure deficit, the situation is reversed, and here failure to act is the more costly mistake. If we plan based on the model's flat trajectory and the observed rise continues, the cost will be an undersized reservoir, undersized irrigation capacity and underestimated drought damage – precisely in a sector where subsidy-policy commitments ex-

tend over decades, meaning the error will remain with us for years. The cost of the opposite error is overcapacity, which is expensive but reversible. The current, model-based planning carries the greater risk.

MAP II/8

Change in summer (June–August) precipitation totals, 2006–2025 vs 1971–1990, by grid point.



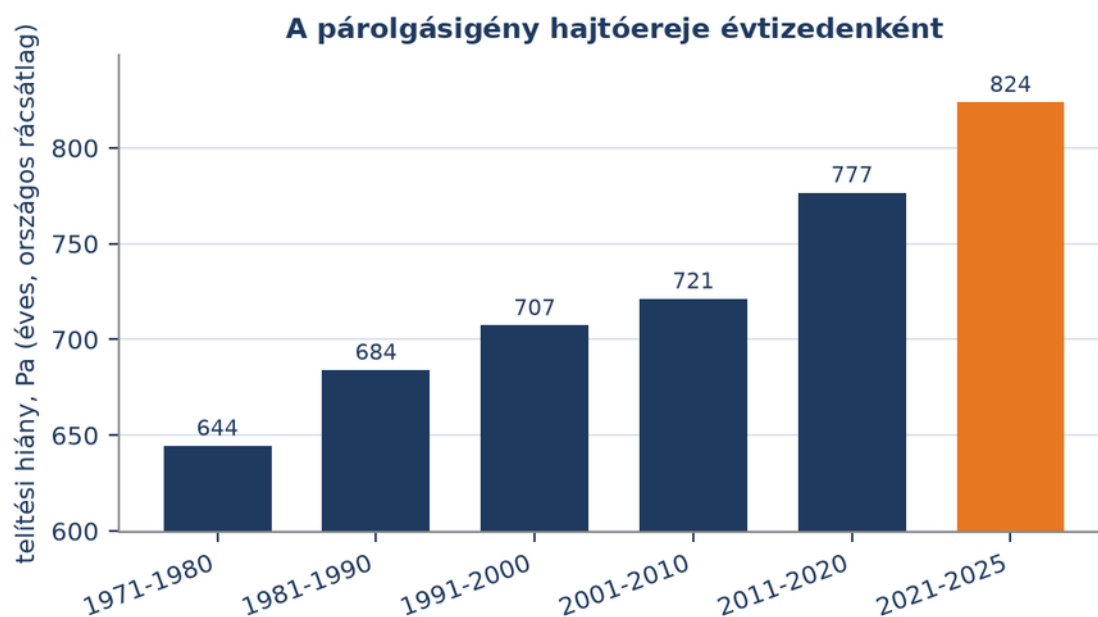
Change, %. Summer: June–August. Time periods: 2006–2025 vs 1971–1990.

SOURCE Own calculations based on the official homogenised daily precipitation grid.

NOTE The national median is –3.2 per cent, but the range extends from –23 per cent to +24 per cent, meaning that the spatial variation is greater than the signal. This map deliberately shows the weak result – there is no coherent national summer drying trend within this time window, and anyone who reads such a trend into it is claiming more than the data supports. Two caveats regarding interpretation: the late window includes the wet 2001–2010 decade, which dilutes the sharp decline seen in recent years (the 2021–2025 summer average is 150 mm, the lowest value in the fifty-five-year series); and grid-point-level extremes do not represent national trends.

FIGURE II/9

The driving force behind evaporative demand (vapour pressure deficit, annual national grid average) by decade.



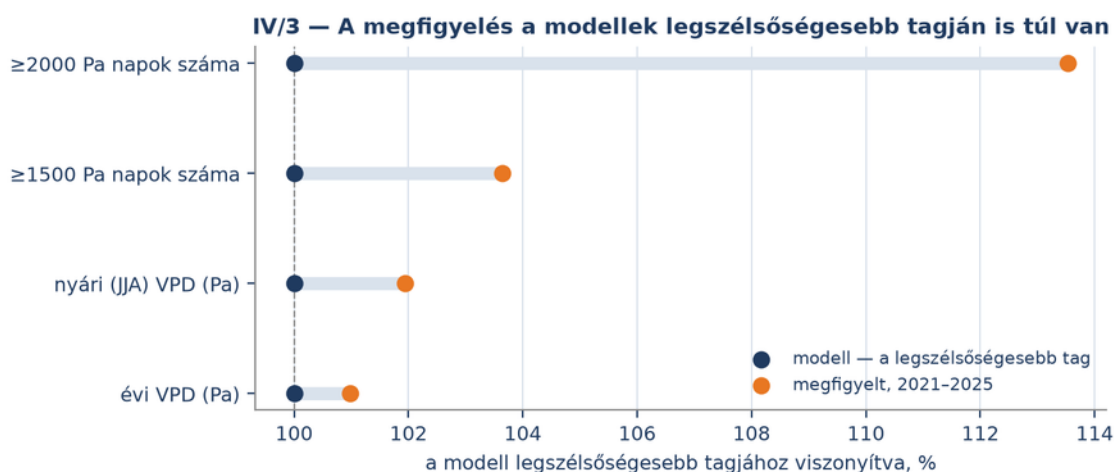
Vapour pressure deficit, Pa. Decadal averages, 1971–2025; the most recent decade is incomplete.

SOURCE Own calculations.

NOTE The most recent, partial decade is shown in orange.

FIGURE II/10

The observed 2021–2025 value compared to the most extreme of the 28 model runs, across four indicators.



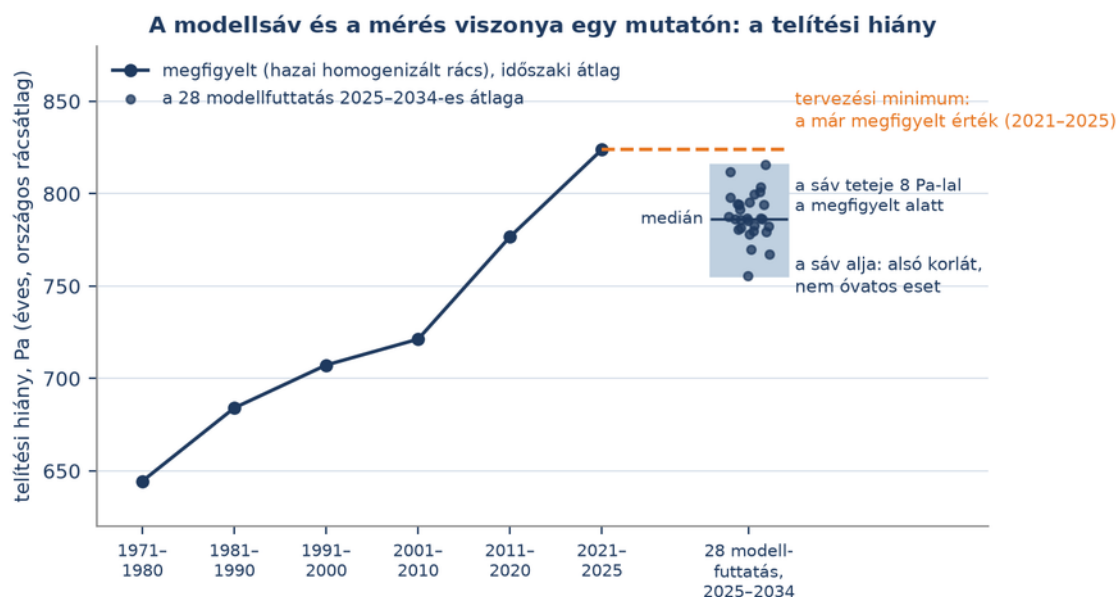
Expressed as a percentage of the model's maximum value (100% = maximum value). All four indicators are VPD-based, not temperature-based.

SOURCE Own calculations: the maximum of the 28 model runs compared to the observed 2021–2025 value, for four VPD-based indicators (annual VPD, summer VPD, days with VPD ≥1500 Pa and days with VPD ≥2000 Pa).

NOTE The 100 per cent line represents the most extreme member of the model; the orange point represents the observation. For all four indicators, the observation lies outside the model range.

FIGURE II/10A

Relationship between the model range and the observation for one indicator: the national grid average of the annual vapour pressure deficit.



Pa. On the left are the observed period averages from 1971; on the right are the averages (dots), the range (min–max) and the median of the 28 model runs for 2025–2034.

SOURCE Own calculations: observed VPD from the observed branch of FORESEE-HUN v1.4, an MT-CLIM estimate from the HungaroMet homogenised grid (1971–2025, period averages); the annual average for 2025–2034 from the 28 FORESEE-HUN runs (14 model pairs $\times$ RCP4.5 and RCP8.5). Figure data: f1_vpd_sav_meres.csv, f1_vpd_sav_meres_obs.csv.

NOTE The orange dotted line represents the value already observed in 2021–2025 (823.9 Pa): this is the planning minimum. The range of the 28 runs lies between 755 and 816 Pa, with the upper limit 8 Pa below the observed value; the lower limit of the range (755 Pa) is a lower bound, not a conservative estimate. The same data as in Figure II/10, showing the full range and the time series.

II.3 Frost – the least obvious chapter

The number of days with frost is clearly decreasing: from 93.8 days in the 1970s to 77.8 in 2021–2025, a reduction of sixteen days. The trend is -4.21 days per decade, and the 95 per cent confidence interval $[-6.67; -1.74]$ does not cross zero.⁶² This trend also fails to meet the multiple-test threshold for this section (see the methodological details). However, it does not follow from this that the risk of frost is decreasing.

The decrease stems from both ends of winter, not from spring. In the same dataset, the number of frosty days in April–May **shows no trend whatsoever**. The confidence interval encompasses zero across all three time windows examined, with p-values ranging from 0.63 to 0.96. There is a structural reason for this discrepancy. Warming reduces the number of frost days where a large portion of the temperature distribution shifts above zero degrees – at the beginning and end of winter. Late-spring

frosts, by contrast, are a rare phenomenon driven by atmospheric circulation: cold advection over an already warmed landscape. Their frequency is determined not by the annual mean temperature, but by the circulation – that is, precisely the mechanism on which the literature is divided, as discussed in section II.5.

This picture is complemented by phenological data. According to a heat-sum-based proxy for budburst – the cumulative heat sum from 1 February, based on three thresholds – budburst has **shifted forward by twelve days**: from day 96.7 of the year in the 1990s to day 84.6 in 2021–2025 (–1.95 ... –2.10 days per decade). The date of the last spring frost, based on the same data, changed from 101.8 to 101.5, meaning it remained virtually unchanged. The decade-averages for the exposure window between the two are: 12.0 · 5.9 · 5.4 · 4.1 · 9.2 · **16.8 days** (from 1971–1980 to 2021–2025).

This is where we need to be most careful. It would be tempting to write that ‘the frost risk window is widening’. **However, this cannot be considered a trend, as the fifty-five-year trend for the window is +0.22 days per decade, $p = 0.82$ – meaning there is no trend. The data show that the lowest value in the series of decades is for 1991–2000 (5.4 days), the highest is for the most recent, partial decade (16.8 days), and the number of frost days following bud burst in the 2021–2025 period represents the highest decade-level value in the series for all four indicators examined – 1.6 times the norm for mild frost and 3.5 times the norm for damaging frost (below $-2\text{ }^{\circ}\text{C}$). This is a five-year observation; it is neither a trend nor a forecast. We therefore do not claim that this represents an increase, but we do report the outlier values from the last five years – because this is relevant from a planning perspective, and omitting it would be just as much of a mistake as treating it as a trend.**

METHODOLOGICAL DETAIL

Two further limitations arise from the internal audit. (1) The result depends on **how we aggregate the data**, and the difference is significant – the window calculated as the difference between national averages widens from 5.4 to 16.8 days, while the more conservative indicator, calculated at grid points and clipped to zero, widens from 8.3 to 17.1 days. (2) This section runs numerous statistical tests on the same data, and none of the trends in the common test suite (Annex B, point 7) reaches the adjusted threshold – not even the decline in the annual number of days with sub-zero temperatures, even though the confidence interval for that does not cross zero ($p = 0.0012$). We therefore present all trends in this section in descriptive form.

According to the model-based comparison, spring frost is also an indicator for which the model range does not cover the observations (H.2), and the discrepancy is more pronounced than expected. The fourteen runs of

the regional model ensemble reproduce the annual number of frost days well (member mean 77.1 compared with the observed 77.8) – but not the spring figure. The range of model runs lies between 0.84 and 2.03 days; both the observed mean (2.39) and the value for the last five years (3.48) fall outside this range. Even the highest member is below the norm. The same pattern is evident for the date of the last frost, where the upper limit of the range (96.2) remains below the observed norm (98.8); thus, the model places the last frost **earlier** than is observed.

From a planning perspective, the key point is that budburst is brought forward, while the calendar date of damaging frost does not shift back proportionally, and the last five years represent the most severe period in the series in terms of frosts occurring after budburst. The decline in the annual number of frost days is a poor indicator for decisions on orchard establishment or variety selection. A reduction in frost protection capacity over the next decade is premature – but the extent to which this should be scaled cannot be deduced from this data, and we do not claim otherwise. The chain’s exposure and damage phases are also incomplete. We found no national summary of the area of orchards exposed to frost; the proportion of frost damage compensated for is reported in Section IV.3 (between 2012 and 2024, this accounted for 13.9 per cent of damage mitigation). The cost of these two types of error differs significantly: the cost of maintaining frost protection capacity is visible on an annual basis, while its reduction could result in the loss of an entire year’s harvest following a single poor spring. We carried out this comparison.

II.4 Two-way extremes

In 2026, temperatures of -18.3°C and $+42.0^{\circ}\text{C}$ were recorded in Hungary within the same year; the latter was recorded in Szécsény during the heatwave that began on 20 June, thereby breaking the absolute national heat record.⁶³ This is a planning consideration, as a warming climate does not eliminate cold extremes, but merely makes them less frequent. Preparedness in terms of infrastructure, healthcare and agriculture must be scaled for both extremes, and scaling back preparedness for the cold end of the spectrum in the coming decade would be premature. We do not quantify the cold-side chain (there are no estimates for peak heating demand or cold-related mortality; the mortality model in Section IV.1 does not report on the cold side); the finding therefore indicates the direction but does not provide a quantified value. In our view, scaling back capacity is the riskier mistake here too, because the cost of maintaining

winter capacity is known and reversible, whereas a lack of such capacity would result in supply disruptions during an extreme winter.

The same two-way pattern is evident for precipitation, within a single five-year period. The 2021–2025 five-year period falls below the window average for all precipitation indicators (annual total 551 mm) – *yet* this period includes **the third wettest year** in the fifty-five-year series (2023: 767 mm), while the other four years lie in the bottom third of the ranking (43rd, 44th, 42nd and 52nd out of 55). Describing this five-year period as a ‘dry spell’ misses the point, as it is not dry but rather variable.

This pattern is also evident over the long term, and this is the key finding of this chapter. Based on indices calculated at grid points and averaged nationally, a comparison of the first and last thirty-year windows shows:⁶⁴

Indicator	1971–2000	1996–2025	change
annual precipitation total	582.5 mm	612.8 mm	+5.2%
days with precipitation (≥ 1 mm)	89.3 days	90.0 days	+0.7 %
Daily maximum (Rx1day)	33.5 mm	35.4 mm	+5.8%
five-day maximum (Rx5day)	58.0 mm	63.4 mm	+9.3%
Days with ≥ 20 mm	3.87 days	4.67 days	+20.6 %
Precipitation above the 95th percentile	116.8 mm	142.8 mm	+22.2%

The two windows in the table **overlap for five years** (1996–2000), so the two samples are not independent, and the result is a comparison of the windows, not a comparison of two separate periods. **No trend can be established from this** – none of the indicators across the entire series reaches the usual significance threshold (the smallest p-value is 0.070), and the confidence interval for each one encompasses zero. **However, a pattern can be identified:** the annual total shifted by around 5 per cent, the number of wet days by around 1 per cent, and the amount of precipitation on extreme days by more than twenty per cent. **While the number of rainy days remains the same, an ever-increasing proportion of precipitation is falling on a small number of intense days** – and it is precisely this amount that determines runoff, flash floods and infiltration losses, not the annual total.

The mechanism can be identified, but its consequence cannot. The moisture-holding capacity of a warmer atmosphere increases by around 7 per

cent per °C, which raises *extreme* intensity but not the annual total – the same physics that drives the evaporative demand layer in Section II.2. The two seemingly contradictory aspects are therefore **two consequences of a single mechanism**.⁶⁵ However, this does not lead to the assertion that ‘the model underestimates domestic precipitation intensity’. This analysis makes no such claim.

The model side is consistent in terms of intensity but divided in terms of frequency. The internal variation within the regional model ensemble (the same run, with the same error, across two windows) gives +14.3 per cent for precipitation amounts above the 95th percentile, **with 14 out of 14 members showing a positive value**; +13.6 per cent for days with ≥ 20 mm, again in 14 out of 14 members; for the number of wet days, however, only 8 out of 14 members show an increase. Intensity therefore increases, while the number of rainy days does not.

The model’s values for this variable must not be compared with the observed data – this is the most important caveat of the analysis – because, over the overlapping four-year period 2022–2025, the model mean is wetter than the observed values for **all** indicators (annual total +12.5 per cent, wet days +12.9 per cent, daily maximum +14.9 per cent). These are four years, including a historic drought – this should be regarded as a warning, not as an estimate of bias. It does, however, establish that the minimum rule does not apply to this variable either, as the model overestimates rather than underestimates here.⁶⁶

ONE MONTH, TWO EXTREMES – SEPTEMBER 2024

In the early hours of 21 September 2024, the Danube peaked at 830 centimetres near Budapest, 61 centimetres below the highest water level of 891 centimetres recorded in June 2013. In the same month, the Tisza at Szolnok did not rise above –159 centimetres on a single day, nor did it rise above –176 centimetres at Vásárosnamény: one of the country’s major rivers was subject to flood defences, while the other experienced low flows.⁶⁷ This instance does not prove that such dual extremes are becoming more frequent; it demonstrates that two different types of preparedness may be required during the same period.

II.5 Atmospheric circulation – where uncertainty is the information itself

The explanation given in public discourse for the summer drought of 2026 was a prolonged blocking anticyclone. While this is accurate in terms of the observation, no conclusions regarding the future can be drawn from it.

The scientific literature **diverges** on this point. The model-based approach predicts a decrease in the frequency of European blocking patterns, while the semi-empirical, wave-resonance-based approach predicts an increase. The documented fact that models are known to under-represent blocking acts as a mediating factor between the two. This analysis does not resolve this divergence, and neither approach refutes the other.

The discrepancy is also detectable on a continental scale. In Western Europe, heat extremes intensify by 3.4 °C for every degree of global warming, of which 0.8 °C [0.2; 1.4] stems from a change in circulation – specifically, the increased frequency of southerly winds. None of the 170 simulations from the 32 models examined produces a flow-driven trend comparable to that observed.⁶⁸ The possible mechanism is also known: Eurasian double jet stream configurations are becoming increasingly persistent, and this increase in persistence accounts for almost the entire accelerated heatwave trend in Western Europe.⁶⁹ The authors themselves offer two interpretations, neither of which is reassuring: either the models underestimate the forced response of the circulation – in which case the European summer projections are too conservative – or they underestimate low-frequency natural variability – in which case the rate of change is highly uncertain. **Both results relate to Western Europe and cannot be directly applied to the Carpathian Basin; therefore, in accordance with Rule VI.6, they should be treated as contextual information rather than as domestic evidence.**

A third approach takes a different methodological approach, as it does not make projections but instead analyses the observed trend. Its results indicate that the frequency of the Mediterranean and Central European anticyclonic regime is **increasing** ($p = 0.002$). The observed trend for this regime and another regime with a decreasing frequency falls completely outside the range of the 100-member model ensemble, while for a third regime, seven out of the 100 members show a stronger trend than that observed.⁵⁷ This directly supports the following planning implication and also indicates that preparedness must cover at least the frequency measured today.

Planning implication: arguments based on flow patterns (such as ‘prolonged blockages will become more frequent, so longer droughts are to be expected’) **cannot be used**. Where we discuss flow patterns, we must specify the reanalysis product and the season on which the analysis is based, and avoid trend-based phrasing.

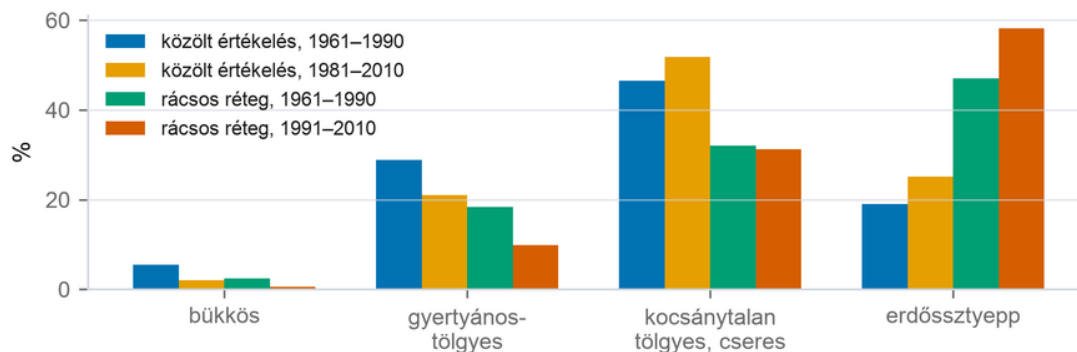
II.6 Independent evidence: shifts in forestry climate classes

Drought is also indicated by a third measure, independent of the previous ones: the forestry climate classification. Hungarian forestry operates with four climate classes: beech, hornbeam–oak, sessile oak or Turkey oak, and forest steppe. These classes are defined by the forestry aridity index. The index is calculated by dividing the average temperature for July–August by the total precipitation for May–August, with July’s figures weighted twice.⁷⁰ It therefore measures the same summer water availability discussed in section II.2, but using different data and a tool from another discipline.

Two national assessments are available, and both point in the same direction. **According to the published national assessment, between the periods 1961–1990 and 1981–2010, the proportion of beech forest climate decreased from 5.5 to 2.1 per cent, while that of hornbeam–oak forest climate fell from 28.9 to 21.0 per cent.** The proportion of sessile oak and Turkey oak forests increased from 46.5 to 51.8 per cent, while that of forest steppe increased from 19.1 to 25.1 per cent. The author attributes this change primarily to rising temperatures.⁷⁰ The layer of the National Adaptation Geoinformation System compares the periods 1961–1990 and 1991–2010 on a 0.1-degree grid using a different database.⁷¹ Of the 1,104 grid cells, 256 – that is, 23.2 per cent of the cells – were reclassified into a drier category. In 122 grid cells, Turkey oak–sessile oak woodland became forest steppe; in 114, hornbeam–oak woodland became Turkey oak woodland; and in 20, beech woodland became hornbeam–oak woodland; there were no shifts towards wetter conditions within the layer.

II/11. ábra. Mindkét hazai értékelés szárazabb erdészeti klímaosztályok felé tolódik, az arányokban viszont eltérnek.

Az ország területének, illetve a rácscelláknak a megoszlása klímaosztályonként, %.



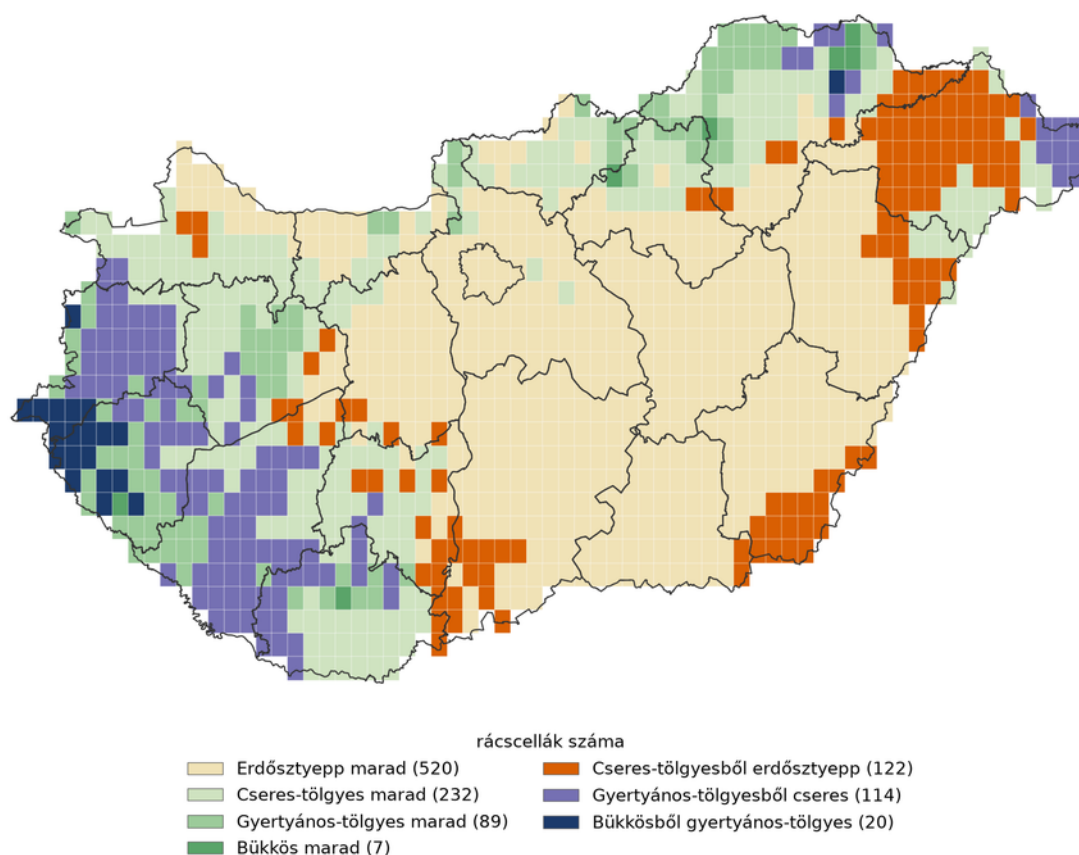
Megjegyzés: A két értékelés adatbázisa, térbeli felbontása és második ablaka eltér; az irány közös, az osztályarány forrásfüggő.

Forrás: Führer (2017), Erdészeti Lapok 152(6); a nemzeti alkalmazkodási térinformatikai rendszer rétege, saját összesítés 1104 rácscellából.

The two assessments agree in terms of direction, but differ in the proportions of the classes. The grid-based layer already classifies 47.1 per cent of the grid cells as forest steppe climate for the period 1961–1990, while the published assessment classifies 19.1 per cent of the country's territory as such. The discrepancy may be due to differences in the database, spatial resolution or the application of class boundaries; the layer description does not specify the methodology. For planning purposes, therefore, the general trend and the spatial pattern can be used, while the proportion of classes should only be cited with reference to the source. The transition is not scattered across the landscape but occurs in blocks. The two largest contiguous blocks are the Nyírség and the Upper Tisza region, and South-West Transdanubia (the latter splits into two blocks close to one another); two smaller blocks are located in the Southern Great Plain, on the Békés–Csanád Ridge and in the southern part of the area between the Danube and the Tisza. In contrast, the transition was scattered along the edges of the northern mountainous region, with roughly one-eighth of the cells there having changed. The second time window for both assessments ends in 2010, so neither includes the warming that has occurred over the past one and a half decades since 2011. A limitation regarding the origin of the data is that both the grid-based layer and the analysis's own observation grid are homogenised and interpolated products of HungaroMet. This evidence is therefore methodologically independent of the previous chapters, though it is probably not independent in terms of its data basis – the latter is an assumption, as the description of the layer does not fully disclose the data basis.

MAP II/12

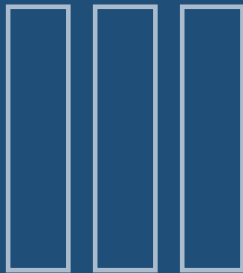
The shift in forest climate classes is block-like: two large contiguous blocks and two smaller ones in the Southern Great Plain are discernible.



Climate classes for 1961–1990 and 1991–2010, on a 0.1-degree grid; the legend indicates the number of grid cells.

SOURCE Layer from the National Adaptation Geoinformation System; the map was compiled in-house from the raw layer retrieved.

NOTE Orange: transition from Turkey oak–sessile oak forest to forest-steppe; purple: transition from oak-hornbeam forest to Turkey oak–sessile oak forest; dark blue: transition from beech forest to oak-hornbeam forest. The pale colours indicate cells where the classification has remained unchanged. The largest contiguous blocks (by lateral adjacency): Nyírség–Upper Tisza region 70 cells, South-West Transdanubia 50 and 47, Békés–Csanádi Ridge 17, and the southern part of the Danube–Tisza interflow 17.



Water

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KEY FINDINGS

New – domestic measurements	Precipitation in the winter half-year did not decrease (249 → 251 mm), while that in the summer half-year fell from 367 to 312 mm.
New – domestic measurements	Groundwater levels are falling at 94 per cent of the 763 wells in the national network of observation wells, and at 98 per cent of those east of the Danube; the previous cyclical recharge has not occurred since 2014; there is no sustained decline in the Western Transdanubia region.
New – domestic measurements based on satellite data	According to satellite gravimetry, total water storage in 2020–2025 was approximately 100 mm below the 2004–2009 level.
New – domestic measurements	In 2026, the summer discharge of the Körös and Maros rivers was the lowest recorded since 2000 at all gauging stations surveyed.
Institutional gap	A significant proportion of water abstraction is unmeasured; consequently, the abstraction side cannot currently be ranked.

III.1 Reserves are dwindling, but not because of the amount of rainfall

This chapter most fundamentally challenges the conventional view, as the depletion of water resources and trends in precipitation are shown here to be separate phenomena.

Precipitation during the winter half-year **did not decrease significantly** by the end of the measurement period (the 1991–2020 normal is 249 mm, while the five-year average for 2021–2025 is 251 mm). Nevertheless, groundwater reserves are dwindling. This statement requires two clarifications, as without them it sounds more emphatic than it actually is. (1)

The figure refers to the winter half-year, not the annual total and certainly not the summer – during the summer half-year, precipitation fell from 367 mm to 312 mm over the same two periods. (2) The data series ends in 2025, so the summer of 2026 – during which the national total rainfall was one-third of the norm (II.2) – is not included in this figure. The statement ‘precipitation has not decreased’ is therefore not a general reassurance, but a measurement relating to a specific window in a specific season – and it is precisely for this reason that it is important, because reserves are still being depleted. Of the 763 wells in the national network of permanent observation wells, which have at least twenty-two years’ worth of August measurements, 721 are falling, and for 600 of them, August 2026 marks the lowest value in the well’s own time series; in the well groups of the six regions examined in detail, all 111 wells are falling in the same direction.

The third clarification concerns the structure of the sentence, as without it the statement asserts more than is necessary. **A constant total precipitation does not imply a constant input.** From the perspective of the water table, the input comprises three components: quantity, state of aggregation and intensity-timing. The above value refers only to the first of these. The state of aggregation has measurably deteriorated (we shall return to the days with snow cover later). Regarding the intensity pattern, the national projection states that the number of days with precipitation is decreasing, while daily maximums are increasing – this is a modelling result, not a shift observed in the measurement series (II.2). Gentle, soaking rain and intense showers do not contribute equally to the water table. **However, the shift in the ratio of runoff to infiltration is not measured in domestic data;** it depends on soil type, and for sandy soils, the literature shows conflicting results. On semi-arid sandy soils, recharge may in fact depend on intense events, as these bypass evaporation losses (the three caveats in section III.4 apply here). By making this distinction, we therefore prevent misinterpretation; we do not elevate a mechanism to the status of a fact, as a statement regarding the total does not necessarily imply one regarding the input.

The crux of the explanation is that recharge only begins above a certain precipitation level – and this level **varies by region, not nationwide.** Based on data from twenty-four winters recorded by the Homokhátság monitoring network, there is a moderate correlation between winter-half-year precipitation and the January groundwater level, from which a net zero recharge of **approximately 185 mm** is derived. The same calculation also shows that the average for the winter half-year in that area is

around 239 mm, meaning it is above this level. In the middle third of average winters, the median water table rises by a few centimetres in five out of eight winters. A significant rise is seen only in the **wettest third**, where, however, it is substantial – more than twenty centimetres. The basis for the calculation, covering twenty-four winters:⁷²

one-third of the winter half-year	Oct–Mar precipitation	change in the median water level from Aug. to Jan.	winters with a rise
lower	121–209 mm	–7.8 cm (falling)	3/8
middle (around the local average of 239 mm)	212–255 mm	+2.5 cm	5/8
upper	272–385 mm	+24.0 cm	7/8

In other words, the point is not that an average winter does not replenish anything, but rather that **replenishment is concentrated in abundant winters**, and an average winter barely raises the groundwater level. This is a stronger claim, because if the growth of the water table depends on a few exceptional seasons, then conservation efforts must be directed towards those seasons – and a missed abundant winter cannot be made up for by an average one.

The figure of 185 mm should be understood as a range, as the correlation is of moderate strength and two winters stand out markedly from it. In one of them, even 227 mm resulted in a rise of almost seventy centimetres, because the previous year's record rainfall had pre-moistened the soil; in another, however, not even 385 mm brought about a rise, because it was a snowy, late winter and the thaw occurred after the measurement. Infiltration is therefore governed at least as much by **the soil's prior moisture content and the timing of the rainfall** as by the seasonal total. Design should therefore not be based on a single threshold value.

The national precipitation picture is consistent with the above, but should be interpreted with greater caution. Winter-half-year precipitation actually increased nationally: the decadal average rose from 228 mm in the 1970s to 258 mm in the period 2011–2020. In contrast, precipitation in the summer half-year fell from 363 mm to 348 mm, then to 312 mm in the 2021–2025 sub-period, with summer precipitation in the same time-frame standing at 150 mm – **the lowest value in the fifty-five-year series**. This is precisely the shift described in professional discourse: precipitation is shifting towards the winter half-year, while evaporative demand are increasing during the summer half-year.

On the precipitation front, however, we must be rigorous in our analysis, and we are committed to this. We carried out a breakpoint analysis on six national time series. The break in temperature is **detectable and robust**: the annual mean temperature shifted step-wise to a level 1.3 °C higher after 2005, and the mean summer temperature to a level 1.8 °C higher after 1991. In none of the four precipitation series, however, can a break be detected, because the bulk of the above-mentioned shift has occurred in the last five years, and five years is not statistically sufficient to confirm a level shift.

The two possible errors here are not symmetrical. If we were to report this as a confirmed shift, we would be making a claim that the data do not yet support. If, on the other hand, we were to remain silent, we would be concealing a signal—visible in every decade-long average—that is relevant from a planning perspective. We therefore report the period averages, highlight the record value for 2021–2025, and indicate that it cannot yet be tested as a level shift.

There is also a second mechanism for recharge, and this has deteriorated. In addition to the amount of precipitation during the winter half-year, the length of time it remains on the surface as snow is also a factor, as a slowly melting snow cover allows time for the water to infiltrate. At the Great Plain stations of the water management hydrometeorological network, the median number of days with a snow cover **fell from 22 to 6 between 2003–2014 and 2015–2026**, and has decreased at all seventeen stations examined.⁷³ Two caveats must be noted:

- (1) The network covers the Great Plain, not the whole country; therefore, this figure cannot be cited as a national statement – though it is sufficient for the argument at hand, as it concerns the region of groundwater recharge.
- (2) The net effect of a shorter snow cover on infiltration has not been established, as the literature is ambivalent: frozen soil inhibits infiltration, so a retreat of the frost line might even improve it. The measured change (22 → 6 days) is unaffected by this, and while the mechanism is plausible, it has not been measured.

A scope restriction applies to the entire chapter. The 185 mm threshold, the 239 mm local average and the above-mentioned division into thirds **relate to the Homokhátság monitoring network**, based on data from 121 grid points and 57 wells. This is not a national figure, and the Homokhátság is not even the worst-affected region – when the six regions are compared using the same method in a single analysis, it ranks

third in terms of rate of decline, with the Nyírség leading at +66.8, followed by the Danube–Tisza–Maros region at +61.4 cm per decade, the Homokhátság at +60.9, and bringing up the rear is the Transdanubian control region at +37.4 (the rate of decline is shown here with a positive sign). In this analysis, the Homokhátság is treated as one of the six regional units examined, rather than as a specific case study. The trend is consistent across the six well groups: the groundwater level is falling with the same sign at all 111 wells, including the Central Transdanubian group; the differences in rate are smaller (between +37 and +67 cm per decade) than any region-centred description would suggest.⁷⁴ However, this cannot be described as a nationwide trend, as the same method does not indicate a decline in Western Transdanubia, in Zala and Vas counties (see the end of this section). The Homokhátság region's own group of 57 wells, with stricter coverage criteria, yields a lower rate when different wells are selected: +44.3 cm per decade (95 % CI [+24.5; +64.2]). The two values relate to two different sets of wells and therefore cannot be compared; the ranking is based on the uniform trend value. In the group of 57 wells, all 57 wells are showing a decline. **However, the record-low level in August 2026 was not caused by this summer, as seasonal draw-down in 2026 was +27 cm, placing it 9th in the 26-year ranking, well below the figures for 2011 (+90) and 2024 (+60).** The level in January was already at a record low, so the deficit was both inherited and accumulated.

The figure circulating in professional discourse – ‘groundwater levels in the Homokhátság have fallen by 2–3 metres’ – is, when converted to the water levels of wells in the Homokhátság, **an overestimation by a factor of 2.4**: the regional median is 1.15 m over twenty-five years, while the 90th percentile is 2.62 m. The higher figure describes the top decile, not the region.

The six regional well groups were selected according to strict data completeness criteria: measurements were taken at each well every year between 2001 and 2026, in both January and August. The groups cover the main regions of the Great Plain, including the sandy infiltration areas of the Homokhátság and Nyírség and the area between the Körös and the Maros, as well as a control group in Central Transdanubia. While data completeness is thus assured, geographical coverage is not exhaustive; for this reason, we have also analysed the entire public network of standard wells: the 763 wells for which August measurements are available for at least twenty-two years between 2001 and 2026 (Map III/2b). The groundwater level is falling at 94 per cent of the wells, with a median rate

of 41 cm per decade, and for 79 per cent of the wells, August 2026 represents the lowest value in their respective time series. East of the Danube (580 wells), 98 per cent of wells are showing a decline, with a median rate of 50 cm per decade. In Transdanubia (183 wells), the figures are 82 per cent and 14 cm per decade, while at the 18 wells monitored by the West Transdanubian Water Management Directorate, there is no consistent decline: ten are sinking, with a median rate close to zero. The wells in the six regional units show a slightly faster rate of decline than the other wells located east of the Danube (median 56 and 45 cm per decade respectively); however, the direction of decline is the same, so the regional picture does not distort the process but rather slightly overestimates its extent. There are also gaps in the data: the public data portal does not contain sufficiently long time series for the wells of the Körös Region and South Transdanubia Water Management Directorates, while those for the Middle Danube Valley and North Hungary Directorates are incomplete.⁷⁴

Groundwater levels previously fluctuated cyclically: following years of drought, they were raised again by abundant winters. To determine whether this cycle still operates, we examined the wells with long time series – specifically the 495 wells for which annual averages are available for at least nine years across all four thirteen-year periods between 1975 and 2026. For each period, we compared the highest annual average level with that of the previous period (Figure III/2c). East of the Danube (298 wells), the 2001–2013 peak remained at least 25 cm below the 1988–2000 level at 23 per cent of the wells, while at 29 per cent it rose above it; the level had therefore returned to previous levels, for example during the abundant year of 2010. In contrast, during the 2014–2026 peak, water levels in 84 per cent of the wells remained at least 25 cm below the 2001–2013 peak, and rose above it in only a single well; the median shortfall was 61 cm. The previous recovery has therefore failed to materialise east of the Danube since 2014. There was also a decline during the drought of the 1980s (the 1988–2000 peak fell short of the previous one at 42 per cent of wells), but this was offset by the abundant winters of the 2000s. In Transdanubia (197 wells), there is no such sharp decline; in every period, the peak falls short of the previous one at 35–44 per cent of the wells, meaning that the decline there is gradual. The comparison is descriptive; the 25 cm threshold is arbitrary, but the conclusion remains the same even with thresholds between 10 and 50 cm.⁷⁴

There are aspects not covered by these data. The causes of the decline are multifactorial: **alongside a lack of rainfall and increased evaporative demand**, these include water abstraction, the canal network, afforesta-

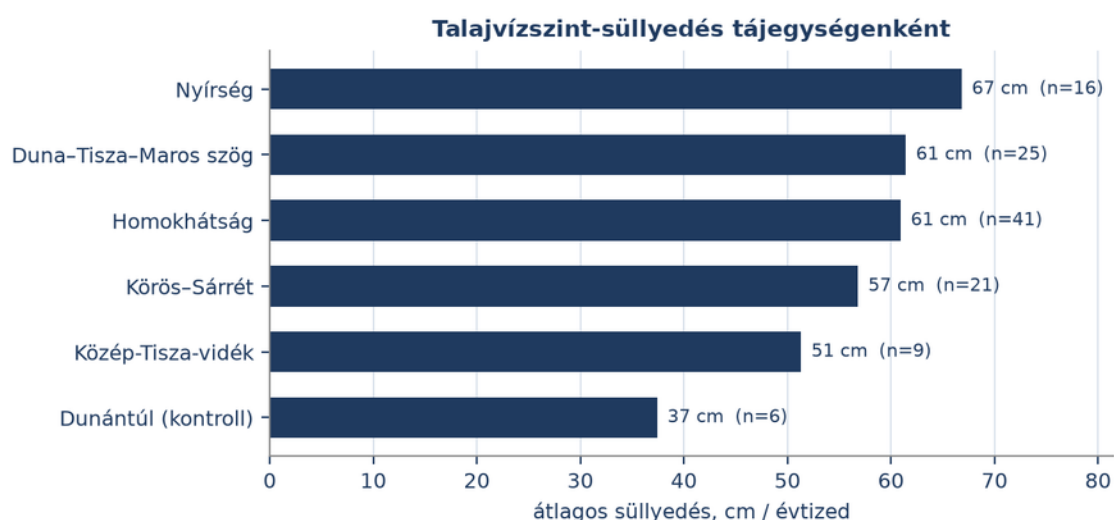
tion and land cover. Domestic studies do not agree on the relative importance of the individual factors. The water balance estimate for the area between the Danube and the Tisza shows a sharp decline in recharge (the difference between precipitation and evaporation).²¹⁴ However, measurements from a forestry sample plot in the Homokhátság indicate that the effect of forests on groundwater varies greatly depending on tree species and location, and cannot be generalised.²¹⁷ Measurements taken at a series of wells gauge the phenomenon, not its cause. The proportion attributable to climate cannot be determined from this. Our contention is simply that the decline is almost universal and reached a record low in 2026 – whatever the driving force, the extent of the risk does not depend on it.

This leads to the chapter's two main policy propositions. **(1) On the in-flow side, the point of intervention is winter-half-year retention, because replenishment is concentrated in abundant winters, and these can only be utilised through retention. Summer drawdown is not exceptional in the twenty-six-year series; the deficit is inherited and accumulated.** **(2) On the withdrawal side, however, a ranking cannot be established before the withdrawal is measured.** A significant proportion of water abstraction is unmeasured, as abstraction from unauthorised wells does not appear in any official time series and typically taps into shallow groundwater – the very water whose level is falling. There are no direct measurements of this; we infer it from the absence of official time series and the location of the decline. There is no public official summary or map detailing the number and location of unauthorised wells. The statutory deadline for applications for continuation licences was 31 December 2023; however, no summary of the applications has been published, nor is the spatial distribution of authorised wells publicly available. While this remains the case, two measures cannot be justified: the down-playing of irrigation restrictions and the expansion of irrigation based on groundwater. Making water abstraction measurable (IX.2) is therefore not a supplementary recommendation, but a prerequisite for every decision on the abstraction side. There is a measured estimate in the Hungarian literature of the cost of the groundwater decline in terms of crop yield; this is presented in Chapter IV.3. The cartographic background for the abstraction side is provided by Map III/2a. The majority of the sinking wells are located where, according to official modelling, the net groundwater flow is low; consequently, shallow groundwater makes up for abstraction only slowly.

Statistical caveats can also be applied to the ranking. The argument that ‘the summer drawdown in 2026 is only the ninth out of twenty-six years’ measures a single-year anomaly, whereas chronic abstraction is a baseline load that is factored into every year’s drawdown and is therefore not visible in the ranking. The record value in January does not exonerate the abstraction side, because the inherited deficit itself has accumulated along with every other factor.

FIGURE III/1

Average groundwater level decline by region, cm/decade; n = the number of individual wells in the well group.



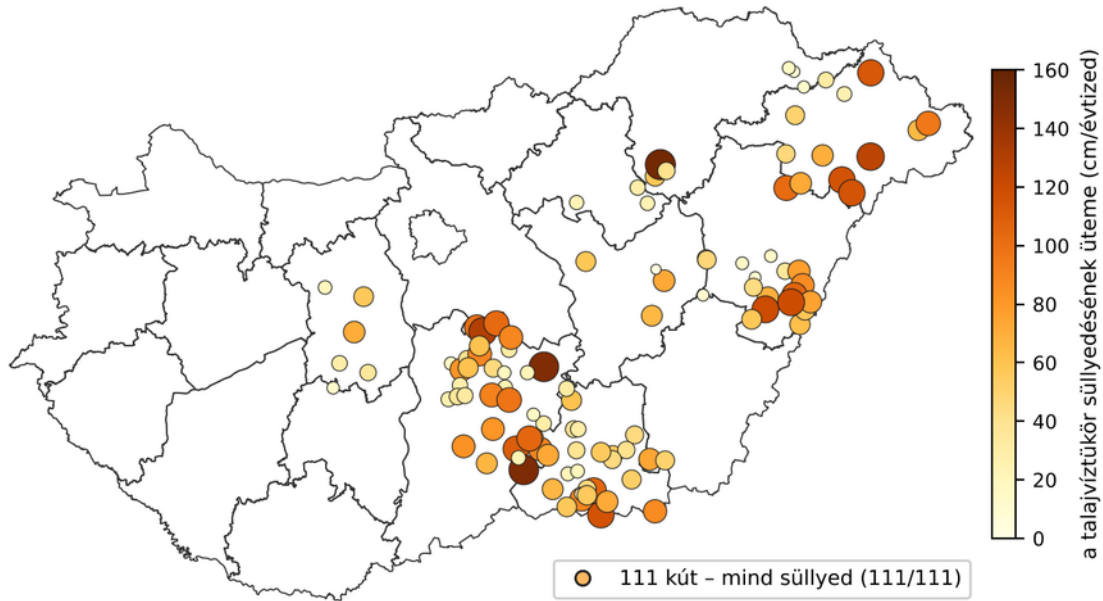
cm/decade. Six regional well groups, 111 main wells.

SOURCE Own calculations based on the main well series.

NOTE In all six regions, every well is moving in the same direction.

MAP III/2

The 111 reference wells of the six regional well groups, showing the rate of groundwater level decline (cm/decade).



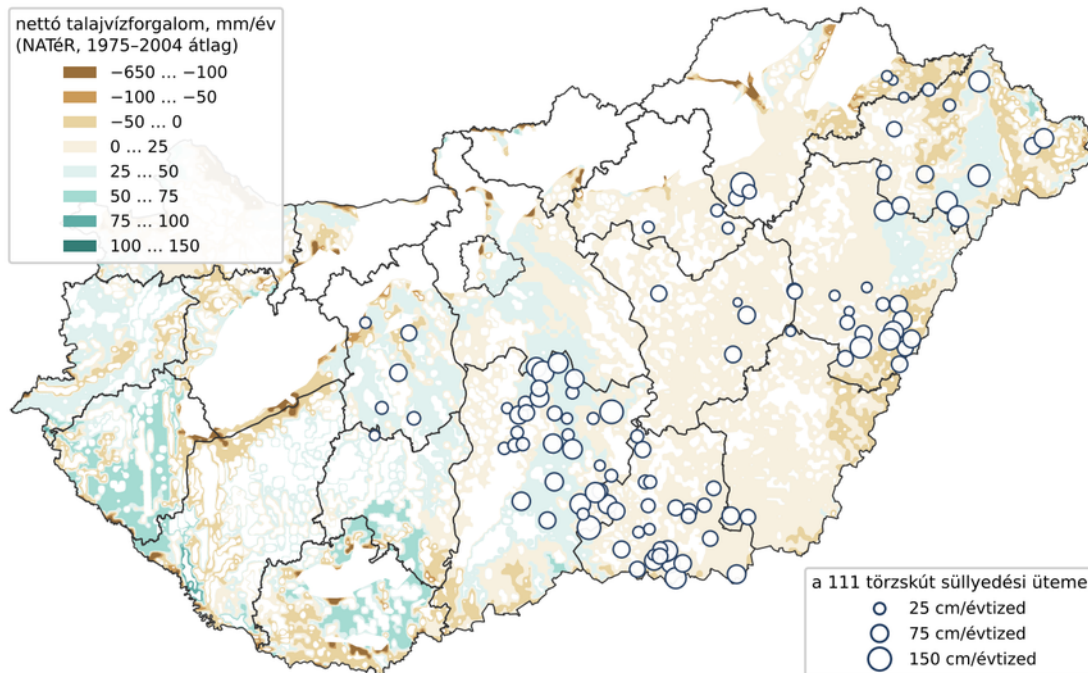
cm/decade. 111 reference wells; national and county boundaries: NATÉR.

SOURCE Own calculations based on official master well data.

NOTE The size and colour of the points represent the same quantity, so that the map remains legible even in shades of grey and for those with colour vision deficiency. All 111 wells are moving in the same direction.

MAP III/2A

The 111 sinking observation wells on the map of net groundwater flow.



Background: the NATÉR subsurface water balance layer – the 30-year average of net groundwater flow calculated using the CARPATCLIM-HU database in a national 3D flow model, 1975–2004, mm/year. Points: the 111 main wells of the six regional well groups, shown with their rate of decline (cm/decade).

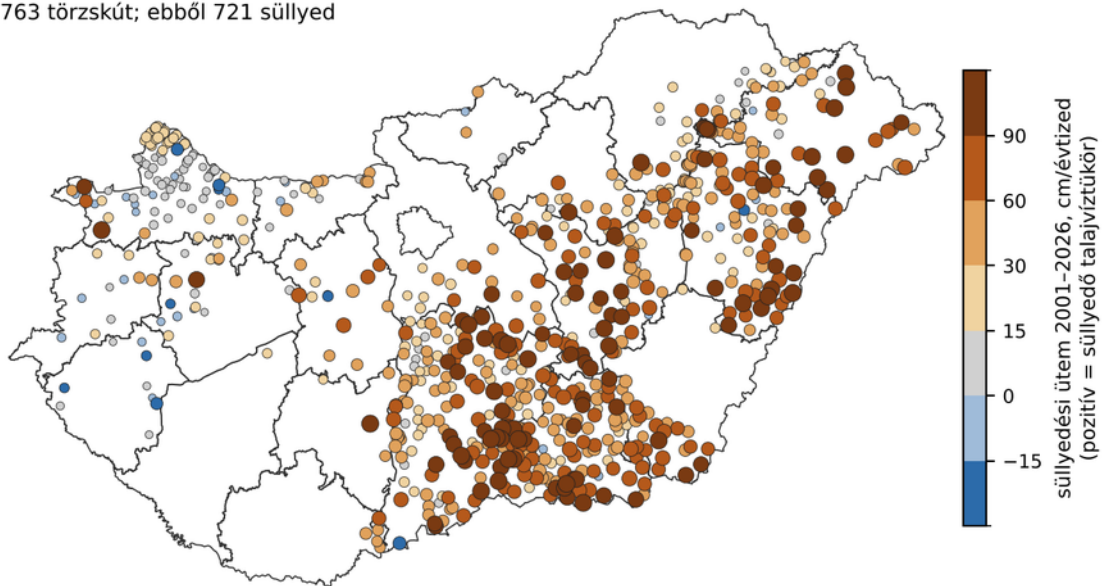
SOURCE NATÉR (nater.mbfisz.gov.hu), groundwater resources, net groundwater flow layer (TVF_CC_75_04); wells: own calculations based on official master well series (Map III/2).

NOTE The brown categories represent net discharge (drainage) areas, while the green ones represent net recharge areas; in the white areas, the layer provides no value (approximately one-fifth of the country's territory, mainly mountainous and hilly regions). More than half of the sinking wells (62 out of 111) fall into the 0–25 mm/year category, while a further quarter (25) are in the –50–0 mm/year category; these are located in the Great Plain and the Mezőföld region, where shallow groundwater flow is low and the system only slowly makes up for the unmeasured abstraction. The background is a model average for 1975–2004; it does not represent the current situation, nor does it show abstraction – that is unmeasured; the map provides the geographical framework for the abstraction-side claim, not the evidence for it.

MAP III/2B

Rate of groundwater level decline at 763 wells in the national network of observation wells, 2001–2026 (cm/decade).

763 törzskút; ebből 721 süllyed



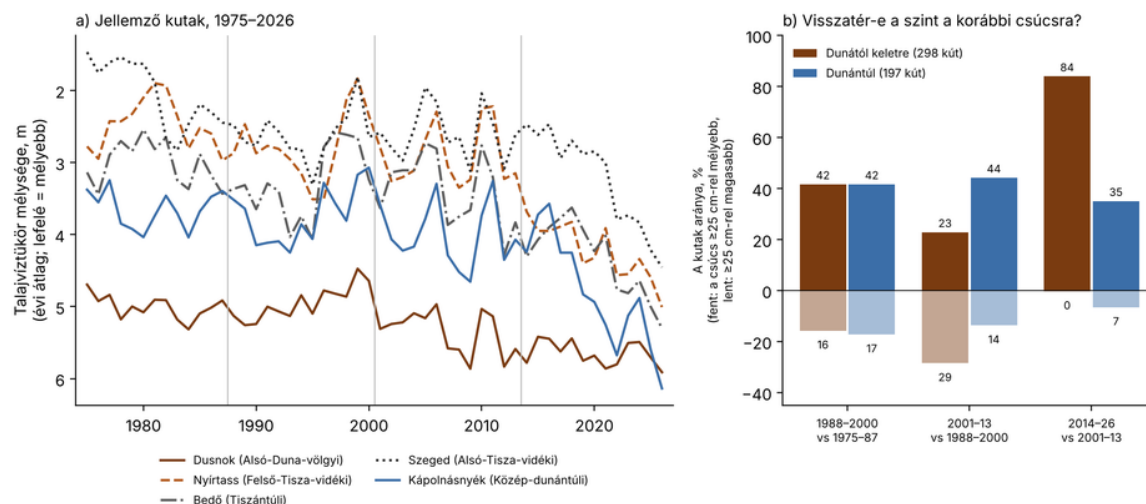
cm/decade, August level, Theil–Sen slope per well; at least 22 years of measurements, the 2026 value is mandatory. National and county boundaries: NATÉR.

SOURCE Own calculations based on the Water Management Authority's public monitoring well data (data.vizugy.hu, retrieved on 12 October 2026).

NOTE Some of the blank patches indicate a lack of data, not a lack of wells: the portal does not contain a sufficiently long series of data for the wells of the Körös Region and South Transdanubia Water Management Directorates. The brown shades indicate a falling groundwater level, while the blue shades indicate a rising groundwater level.

FIGURE III/2C

Cyclical recharge of the groundwater level east of the Danube has not occurred since 2014.



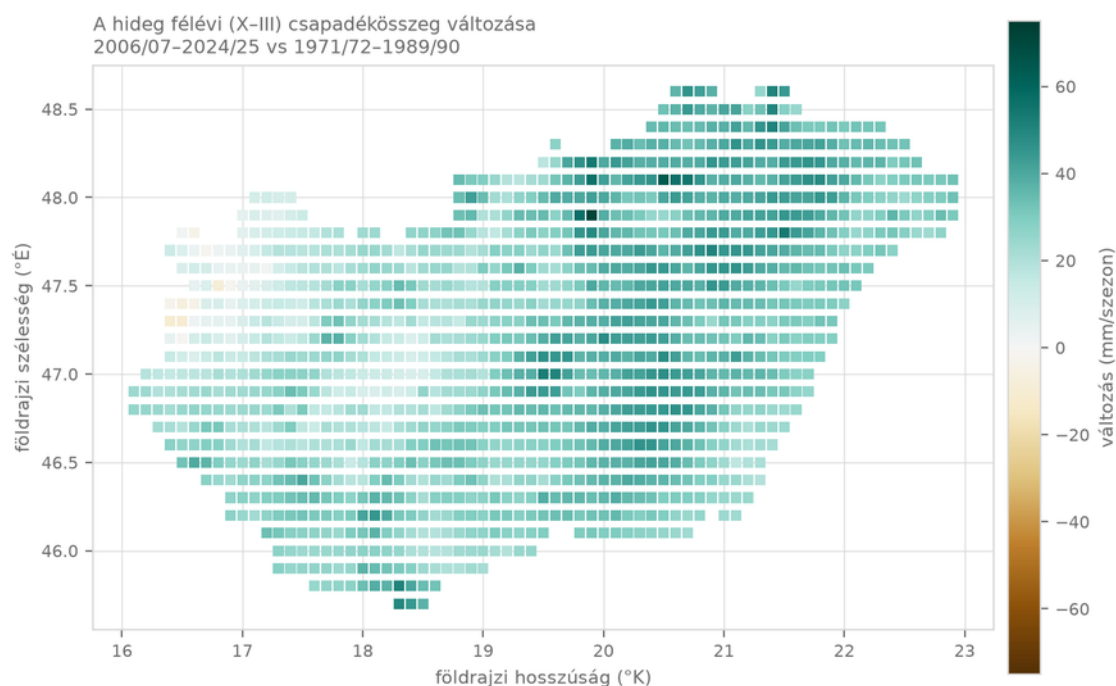
a) Annual average groundwater levels at five representative wells, 1975–2026 (depth below ground level, with deeper levels shown lower on the graph); the vertical lines mark the boundaries of the thirteen-year periods. b) The proportion of wells where the highest annual average level for the given period is at least 25 cm lower (top) or higher (bottom) than that of the previous period.

SOURCE Own calculations based on the Water Authority's public data on reference wells (data.vizugy.hu, retrieved on 12 October 2026).

NOTE The representative wells were selected according to a rule fixed per directorate: from the complete set of wells covering a 52-year series, the one whose shortfall for 2014–2026 is closest to the regional office's median. Panel (b) is based on 495 wells, each of which has at least nine annual averages across all four periods.

MAP III/3

Changes in total precipitation during the winter half-year (X–III), 2006/07–2024/25, compared with the 1971/72–1989/90 reference period, by grid point.



Change, mm. Winter half-year: X–III (1 October – 31 March). Difference between two non-overlapping windows of equal length.

SOURCE Own calculations based on the official homogenised daily precipitation grid.

NOTE The difference between two equally long, non-overlapping windows – not a trend estimate. The increase is almost nationwide, and strongest in the eastern part of the Great Plain: the inflow has improved the most there, where the water supply is in the worst state.

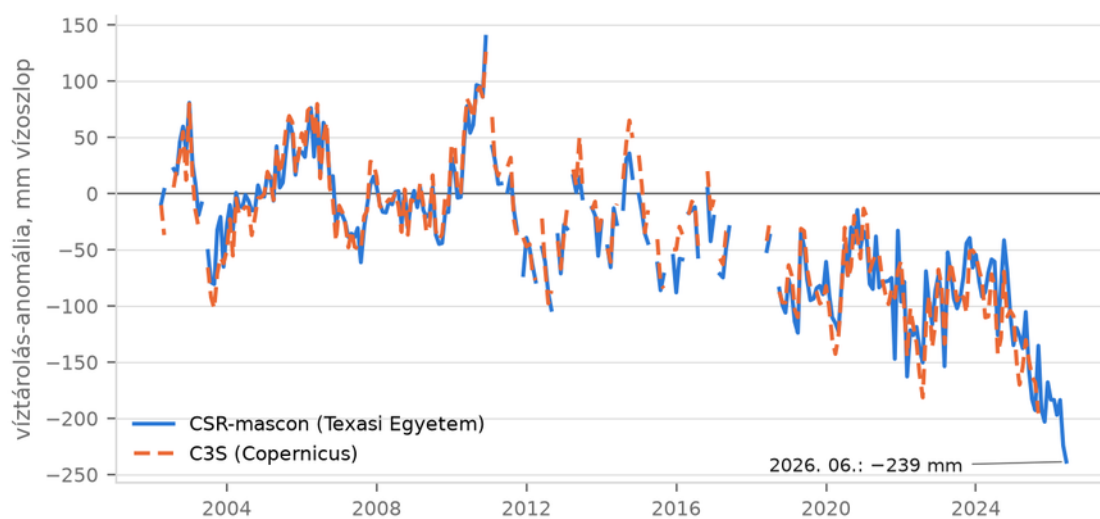
Well levels are data measured at points in a monitoring network. A nationwide picture, independent of these measurements, is derived from the gravitational measurements of the GRACE and GRACE-FO satellite pair, as monthly changes in the Earth's gravitational field can be used to estimate terrestrial water storage – the combined volume of soil moisture, groundwater, surface water and snow.⁷⁵ Two institutionally independent analyses show the same result (Figure III/1a). Compared with the 2004–2009 level, the average for the first section of the series (2003–2010), which includes the reference years, is +3...+5 mm water column; for 2011–2019 it is –26...–36 mm, and –94...–100 mm for 2020–2025. The break in the series occurs after 2014 (2016 in the Copernicus series); the lowest year is 2025, and in the analysis extending to mid-2026, **June 2026 is the lowest month in the entire series**, at –239 mm. In the wider Carpathian Basin, the decline is greater: –124...–125 mm in 2020–2025.

Satellite measurements cannot replace the network of observation wells for two reasons. (1) Their resolution is coarser than that of the country as

a whole, so the value for Hungary also includes signals from neighbouring areas. (2) They measure total water storage but do not show the distribution of the decline between groundwater, soil moisture and surface water. In terms of magnitude, a 100 mm water column across the country's territory corresponds to approximately 9 km³ of water. Taken together, the two measurement methods show that the drawdown observed in the wells is part of a decline in water reserves affecting the entire region.

FIGURE III/1A

The volume of terrestrial water storage across Hungary has been declining in stages since 2014; June 2026 is the month with the lowest value in the series.



Monthly water storage anomaly, mm water column, excluding seasonal cycles, relative to the 2004–2009 average; 2002–2026.

SOURCE Own calculations based on the CSR GRACE/GRACE-FO RL06.3 mascon and the C3S water storage anomaly v1.0 data, averaged over the cells corresponding to the national grid points.

NOTE Two independent analyses: the mascon solution from the University of Texas Space Research Centre (up to June 2026) and the product from the Copernicus Climate Service (up to September 2025). The national value is a regional signal due to the resolution of the satellite measurements.

Study area: the Körös–Sárrét and the Maros, with their counterparts in western Transdanubia

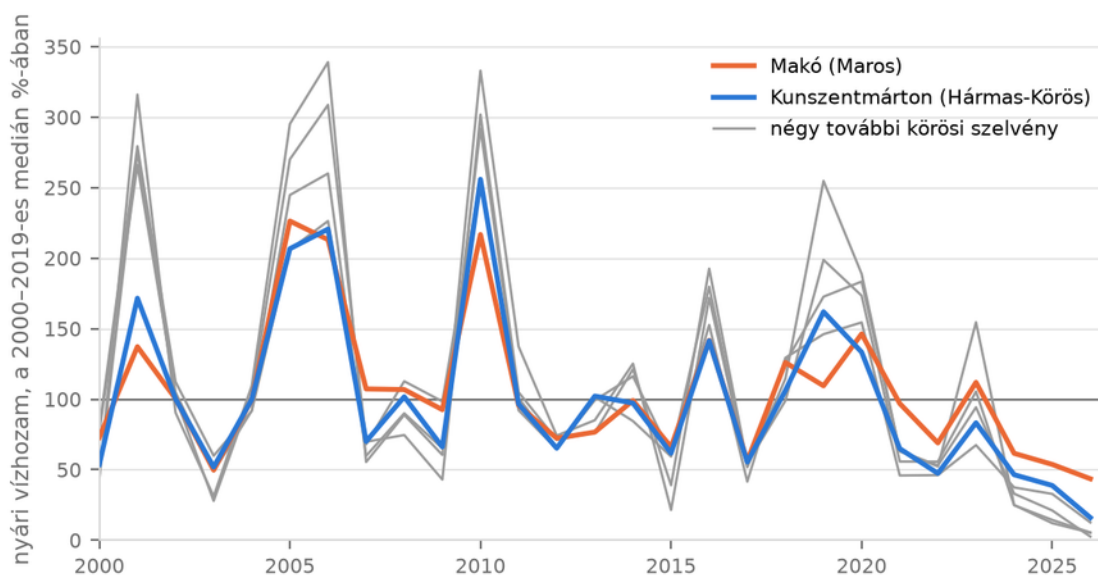
The picture above is composed of national averages and regional well clusters. By tracking a single region, it is also possible to see how surface water, groundwater and crop yields are interlinked. The sample region comprises the Körös–Sárrét and the lower reaches of the Maros, as all three indicators deteriorated simultaneously here between 2024 and 2026. The counterpart is Western Transdanubia – Zala and Vas counties – the country's rainier, oceanic-influenced part.

For surface waters, the decisive figure is the water discharge, i.e. the volume of water flowing through the river's cross-section per second. We

examined six water gauges on the Körös and Maros rivers operated by the Water Management Authority: Gyula, Békés, Körösszakál, Gyoma, Kunszentmárton and Makó. The average water flow between June and September in 2026 was the lowest value in the 27-year series dating back to 2000 at all six locations. Since 2023, it has been lower each year than in the previous year (Figure III/1b).⁷⁶ At Kunszentmárton, on the lower reaches of the Hármas-Körös, the summer median for 2000–2019 was 68.8 m³/s; in 2026 it was 11.0 m³/s, i.e. one-sixth of the median. The flow rate of the Maros at Makó fell from 127.0 m³/s to 55.3 m³/s, and the water level there remained below the lowest level ever recorded by the gauge for five days during the summer of 2026. At the sections regulated by the dam – in Gyula, Békés and Gyoma – the water level hardly changed in relation to the fall in discharge, as the structure maintains the level while less and less water flows through the riverbed. At these points, therefore, the water level does not reflect the shortfall, whereas the discharge does. The summer flow regime of the Hármas-Körös is also influenced by water replenishment from the Tisza: according to a report by the Körös Region Water Management Directorate dated July 2026, most of the water entering the Hármas-Körös arrives via the Tisza-Körös Valley Cooperative Water Management System (TIKEVIR), via the Hortobágy–Berettyó, typically from the upstream reservoir at Kisköre. The Körös rivers' own summer water flow has long been low, which is why the system was built. The water flows at Gyoma and Kunszentmárton thus reflect the operation of the water replenishment system, not just the runoff from the catchment area; the gauges on the upper reaches, at Gyula and Körösszakál, are independent of this, and it was there that we recorded the lowest value in the series. The summer flow of the rivers is jointly determined by the catchment area beyond the border, water management on the Romanian side, damming and water abstraction; the figures above measure the shortfall, not its cause.

FIGURE III/1B

The summer discharge of the Körös and Maros rivers has been decreasing year on year since 2023; in 2026, all gauging stations recorded the lowest value in the series dating back to 2000.



Average water flow in June–September as a percentage of the 2000–2019 median, six gauging stations, 2000–2026.

SOURCE Own calculations based on daily water flow data from the Water Management Authority (data.vizugy.hu).

NOTE The four additional Körös gauging stations are: Gyula (Fehér-Körös), Békés (Kettős-Körös), Körösszakál (Sebes-Körös) and Gyoma (Hármas-Körös). The 2026 value is valid up to 27 September.

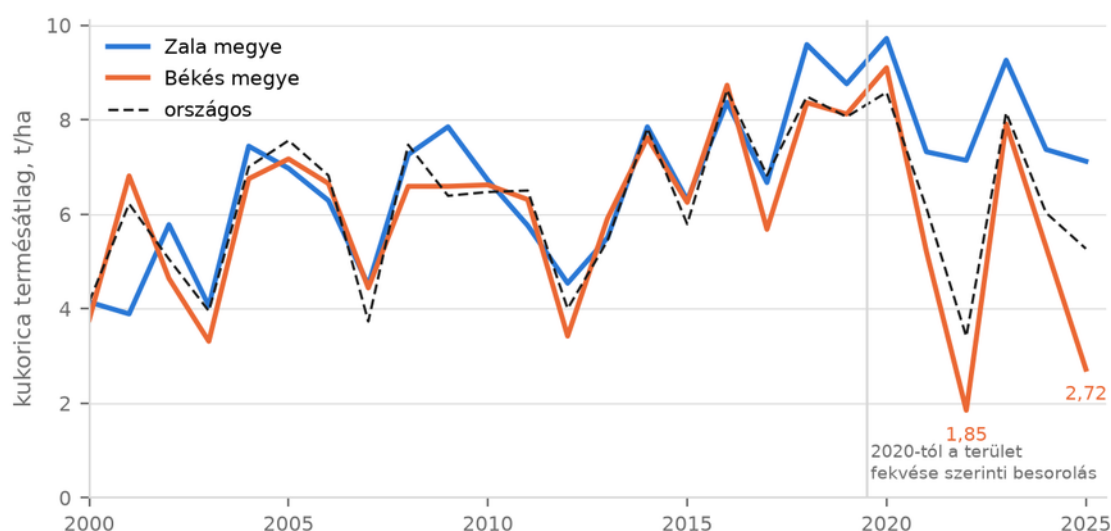
Groundwater levels paint the same picture. At all 21 selected wells in the Körös–Sárrét region, the groundwater level has been falling since 2001, with a median rate of 57.7 cm per decade, and at 15 of the 21 wells, August 2026 marked the lowest level in the past 26 years. In Zala, the same analysis shows a different picture: out of 19 wells, 5 are falling, with a median rate of –5.4 cm per decade; in other words, the groundwater level has risen slightly, and August 2026 marked the lowest value in the series for just one well. Taken together, Zala and Vas counties show the same trend across 25 wells.⁷⁷

In terms of crop yields, the two regions have diverged since 2021. According to county-level data from the Hungarian Central Statistical Office (KSH), the average maize yield in Békés County fell from 6.70 tonnes per hectare in the 2010–2019 period to 4.60 tonnes per hectare on average for the 2021–2025 period, while that of Zala County rose from 7.01 to 7.64 tonnes over the same periods. In the drought year of 2022, the average yield in Békés was 1.85 tonnes and in Zala 7.14 tonnes; in 2025, the figures were 2.72 and 7.12 tonnes respectively. In 2026, according to preliminary data from the harvest committee in Békés, the county average was

1.4 tonnes; data for Zala County was not available at the time of finalising this manuscript.²⁴⁸ Békés thus achieved a quarter and slightly more than a third of Zala's average yield in the two poor years, even though the two counties had followed a similar trend up to 2020 (Figure III/1c).⁷⁸ As the average yield is expressed per hectare, changes in area alone do not explain the decline: in Békés, the area harvested for maize fell by 19 per cent and the total yield by 43 per cent over the same periods; the bulk of the shortfall is therefore attributable to a decline in yield per hectare. In Zala, the area under cultivation fell by 31 per cent, yet the average yield increased (KSH STADAT Table 19.1.2.5). The difference is smaller for wheat; in 2022 and 2025, Békés accounted for two-thirds of the average yield in Zala.

FIGURE III/1C

The average maize yields in Békés and Zala counties moved in tandem until 2020; since 2021, they have diverged in dry years.



Average maize yield, t/ha, Békés and Zala counties, compared with the national average, 2000–2025.

SOURCE KSH STADAT Table 19.1.2.5, own analysis.

NOTE From 2020, the Hungarian Central Statistical Office (KSH) classifies regional data according to the county in which the land is situated; previously, it was based on the farmer's registered office. The difference is linked to dry years and almost disappears in 2023.

Thus, in two parts of the country, the same decade brought about two different water balances. In the Körös–Sárrét region, surface water, groundwater and crop yields all deteriorated, and by 2026, discharge and groundwater levels had reached the worst values in the measurement series. In Zala and Vas counties, the groundwater level is not falling uniformly, and maize yields have not declined. The sequence of interventions must therefore be determined on a region-by-region basis, and the baseline data should not be precipitation alone, but rather the combined

series of discharge, groundwater levels and average crop yields. We recommend this approach based on the above measurements.

III.2 What we do not know – and why this is a problem

Shallow groundwater and deeper confined groundwater present a contrasting picture, and this in itself is a finding. Shallow groundwater has been falling almost everywhere over the entire quarter of a century – a slow, continuous depletion. By contrast, the level of deeper confined groundwater showed no trend for twenty years; the decline only became apparent after 2019, occurring simultaneously across a wide area. Based on a rigorous national well network of 102 wells covering a period of twenty-six years:⁷⁹

window	change	p	level
2001–2019	+0.033 m/decade (no displacement)	0.48	–5.31 → –5.37 m
2019–2026	–1.672 m/decade	0.0002	–5.37 → –6.55 m

Consensus between wells is also window-dependent. Between 2001 and 2019, 56 out of 102 wells showed a decline, which is essentially a random distribution. Between 2019 and 2026, **85 wells showed** a decline, with a median displacement of –0.61 m. Near-surface reserves have been depleting for some time, while the decline in deeper confined groundwater levels is a development specific to the most recent time window.

METHODOLOGICAL DETAIL

The break year is data-driven; therefore, the corresponding probability value must be cited alongside the choice of break year, and the 2019–2026 period only meets the strictest threshold when combined with the 2026 vintage (without it, $p = 0.0014$). **The existence of the trend break, however, is independent of this; it holds for every coverage threshold examined, and the 85/102 sign consistency is not vintage-dependent either.**

The cause of the trend break, however, remains undecided, and this is the most important open question in this chapter. Two interpretations are at odds with one another, and both yield the same curve: (a) the drought period after 2021 extended to deeper confined groundwater, or (b) confined groundwater abstraction increased when surface and groundwater supplies dried up – the confined groundwater is precisely the source to which the demand is diverted. There is also a temporal discrepancy, as the break occurred in 2019, while the drought period in interpretation (a) begins in 2021/22. This does not refute (a) – it may be a delayed response – but nor does it contradict (b). **We cannot decide, as**

there is no production time series. This is a data gap, not an analytical shortcoming, since the climatic and abstraction effects cannot be separated because abstraction is, to a significant extent, unmeasured.

The risk of omission is greater here. If the decision-maker interprets the shift in confined groundwater levels as ‘no evidence’ – perhaps citing the flat trend observed between 2001 and 2019 – they are making a decision regarding a resource that accounts for around one-third of the drinking water supply,²²⁸ and for which it would take decades to rectify any error.

This leads to one of the most cost-effective points of intervention: ensuring that water abstraction can be measured even where it is not currently measured. This improves the quality of all subsequent analyses without requiring any investment.

III.3 Low flows in rivers

The low-flow situation on the Tisza is measurable and documented. Here, we follow a single rule for interpretation: the time window is specified alongside every low-flow value, because the frequencies calculated for the summer window and for the whole year differ significantly, and confusing the two is the easiest mistake to make. In 2026, the annual minimum occurred in January, which raises questions regarding data quality or operational procedures; it cannot therefore be interpreted as a climatic indicator.

The picture regarding the rivers appears clear-cut, and it is precisely for this reason that one must be cautious. At eight gauging stations on the Danube and Tisza between 2000 and 2026, the annual maximum water level has fallen everywhere – by –43.9 cm per decade in Budapest and –105.4 cm per decade in Szeged. **We do not describe this as a trend for three reasons. (1) The number of tests. Eight gauges with two indicators mean a large number of tests, and even the lowest probability value does not reach the threshold applied in the analysis. (2) Water level is not the same as discharge, because riverbed incision results in a falling water level at a fixed gauge even with the same discharge; as measured, this explains about 10–25 per cent of the decrease at the three Danube gauges examined (Nagymaros, Budapest, Dunaújváros) and at Szolnok, and practically none at Tokaj, Vásárosnamény and Szeged. (3) The upper extreme value range. The Danube flood wave in September 2024 reached 830 cm in Budapest – the fourth highest annual maximum of the century.**

METHODOLOGICAL DETAIL

The geometric ratio is a measured value, not an assumption. Based on pairs of water levels and discharge data with matching timestamps, comparing the early and late windows, the shift in the official correlation ranges from –1 to –15 cm per decade depending on the gauge (in Szeged: +2). Of the 40–105 cm per decade decrease in the annual maximum, the geometry therefore accounts for about 10–25 per cent at the three Danube gauges and Szolnok, and practically none at Tokaj, Vásárosnamény and Szeged.

A restriction on the scope of application is necessary, as without it the value could be misinterpreted. This geometric proportion represents a measurement correction for water level readings, not a component explaining the groundwater balance. The lowering of the drainage base level near the channel is a site-specific mechanism that can be interpreted along the margins of the Danube–Tisza region and cannot be generalised nationwide. The findings in this chapter regarding groundwater are based on well networks independent of water gauges; therefore, the geometric correction does not affect them.

The measured proportion resolves two issues. (1) The interpretation that ‘the decline in water level is entirely geometric’ **does not hold** true. (2) Nevertheless, the reservation does not disappear, because the measured ratio is a lower estimate; where the water authority has not reviewed the water level–discharge relationship at a particular gauge, the actual channel incision appears as zero in the calculation.⁸⁰

The two rivers (the Danube and the Tisza) represent two distinct histories, and this is more important from a planning perspective than the question of trends. Measured against official flood alert levels, and comparing the 2000–2012 and 2013–2025 periods, the number of days on Level I alert has fallen by at least half at all seven assessable gauges. Level III days, however, **show a mixed picture**: on the Tisza they have practically ceased to occur (Szolnok 12.1 → 1.5; Szeged 4.0 → 0; Tokaj 3.8 → 0 days/year), on the Danube they remain essentially unchanged (Budapest 1.0 → 0.8), while at Mohács they are on the rise. This should be understood as a comparison of specific periods, not as a trend. The catchment areas of both rivers are international, and approximately half of Hungary’s territory belongs to the Tisza catchment area. The difference lies in how the rivers are fed: the Danube’s flood reserves, which are also fed by Alpine snow and ice reserves, have not disappeared, while the behaviour of the Carpathian, precipitation-driven Tisza catchment, with its lower inertia, aligns with the precipitation pattern described in section II.4 – fewer but more intense events tend to result in flash floods and inland flooding rather than a spring flood wave that raises the water level across the entire catchment. The latter is our own interpretation, derived from the precipitation pattern in Section II.4 and the differing inertia of the two catchments; it has not been verified against discharge data. We present it here because the distinction between the flood risks of the two rivers has planning implications, even if the mechanism has yet to be substantiated.

FIGURE III/4

Summer minimum discharge rates on the Tisza at Tiszapalkonya, 1996–2026, 1 June – 30 August window.



Discharge, m³/s. Period: 1 June – 30 August.

SOURCE Own calculations based on the official hydrological data series.

NOTE The time window must be specified: the frequencies calculated for the whole year differ significantly.

III.4 Heavy rainfall and flooding

The focus on drought must not overshadow the opposite sign of precipitation extremes. The intensity of heavy rainfall is increasing; however, the trend does not reach the usual significance threshold within the analysed window – we report this as it stands, without rounding. Flood risk diverges between the two major rivers, and the risk of flash floods arises not on the major rivers but in the small catchment areas.

Domestic research also emphasises that drought, heatwaves and flash floods share a common root cause in the surface water cycle – a lack of water available for evaporation. The same surface that cannot evaporate water cannot allow it to infiltrate either. An international attribution analysis conducted in 2026 with Hungarian co-authors reaches the same conclusion for the eastern part of the country: the increased demand for evaporation **has brought forward the threshold for drought** – a lack of rainfall that would not previously have caused a drought now leads to one – while rainfall over a six-month period has barely changed.⁸¹

There is a mechanism that we do not describe because there are no measurements for it. It would be obvious to argue that if the same amount of water arrives in increasingly intense events, the proportion of runoff increases and that of infiltration decreases – this would link the

precipitation pattern described in Section II.4 to the depletion of water reserves described in Section III.1. **This cannot be described without three caveats, and all three apply.** (1) There are no domestic data; the water management soil moisture and hourly precipitation network is empty for the period under investigation. (2) The effect is soil-type-dependent, and is least likely to occur on sandy surfaces – where intense precipitation is required for surface runoff to occur at all. (3) In semi-arid, sandy regions, groundwater recharge may in fact depend on *extreme* precipitation, as heavy rain bypasses evaporation losses and provides **greater** recharge.⁸² **The change in the runoff–infiltration ratio is therefore a hypothesis, not a measured result** – the network for measuring it exists, but is empty.

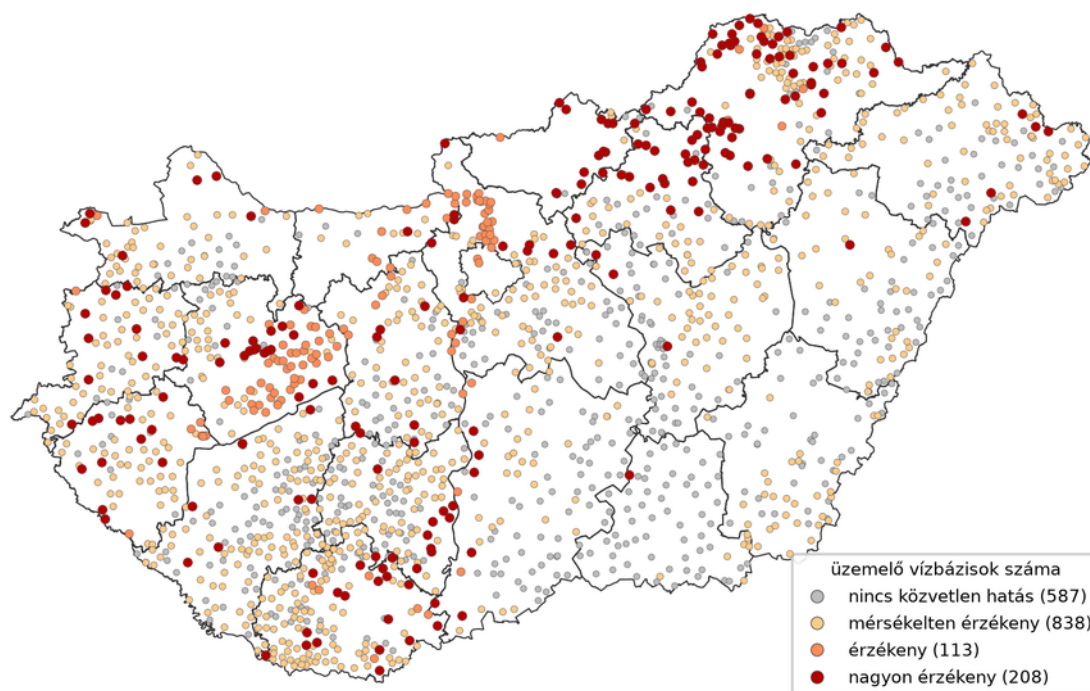
III.5 Drinking water resources, infiltration, flash floods: what the official geospatial information system adds

The depletion of water resources also affects drinking water supply, and the national adaptation geospatial information system provides a nationwide overview of this. The system classifies 2,029 drinking water sources into climate sensitivity categories.⁸³ **Of the 1,746 operational water sources, 208 – or 11.9 per cent – are highly sensitive, while a further 113 are sensitive.** 838 are moderately sensitive, and 587 are unaffected by direct climatic impacts. The categories follow the type of confined groundwater, and sensitivity decreases with depth: the most sensitive category comprises porous confined groundwater shallower than 30 metres, karst confined groundwater with flow channels and surface water abstractions, while porous confined groundwater deeper than 100 metres – all 651 such water resources – fall into the category unaffected by direct climatic effects. The 2020 methodological report reaches the same conclusion: deep confined groundwater are the least sensitive to climatic impacts. There is one point where the report and the national classification differ: the report's table classifies bank-filtered water abstraction as among the most sensitive, while the national classification places it one level lower, among the sensitive categories. Within the total stock, the largest group consists of porous confined groundwater at depths of 30–100 metres (860 water resources), followed by those deeper than 100 metres (651), those shallower than 30 metres (219), bank-filtered confined groundwater (90) and open karst confined groundwater (73). The remaining 137 consist of covered karst (49), fissured (29), passage-type karst (26), surface (16) and other (17) confined groundwater. The con-

fined groundwater type layer contains one more water source, bringing the total to 2,030.

MAP III/5

The majority of highly sensitive drinking water sources are situated on shallow porous aquifers and are concentrated in Transdanubia and the northern mountainous region.



Climate sensitivity categories of operational drinking water sources; the legend indicates the number of water sources.

SOURCE A layer from the National Adaptation Geoinformation System; the map was compiled in-house from the raw layer retrieved.

NOTE Sensitivity is an inherent characteristic of the aquifer and changes slowly; the operational status reflects the time of the survey. Of the 208 highly sensitive operational water resources, 169 are shallow porous aquifers, 25 are karst aquifers with passages, and 13 are surface water abstraction points; the type of one water resource is unclear when the two map layers are overlaid.

At the settlement level, the picture is clearer, but its scope is narrower, as the survey covers the supply areas of the ten major water utility providers included, rather than the whole country. Of the 1,495 settlements assessed (the report's table lists 1,498), 421 fall into the 'highly sensitive' category. The same classification system also assesses the utilisation of groundwater: 11 settlements are classified as 'critically utilised' and 80 as 'heavily utilised'; this classification indicates a sustained decline in water levels in porous confined groundwater deeper than 100 metres. **This is therefore a classification relating to deep confined groundwater used for drinking water, not the abstraction from shallow groundwater discussed in Section III.1; consequently, it does not settle the abstraction-side proposition of Section III.1.** However, it does demonstrate that there

is a national method for classifying the utilisation of groundwater at the settlement level. Two qualifications are necessary. (1) Sensitivity is a characteristic of the confined groundwater and changes slowly. (2) Extraction and operational status, on the other hand, reflect the time of the survey; according to the report, this corresponds to the situation in October 2018. The baseline study was carried out in 2015, and its extension in 2020, involving ten water utility providers.⁸³

The system also provides a baseline condition modelled on groundwater: the 30-year average of calculated infiltration for the period 1975–2004.⁸⁴ According to this layer, on 23.0 per cent of the country's territory, infiltration remains below 15 millimetres per year, and on 56.5 per cent, it remains below 35 millimetres per year. This is a modelled value, representing a different quantity and a different timeframe from the measured data in Section III.1. The two cannot therefore be added together, nor can they be cited as mutual corroboration. The layer provides a national-scale context for the measured regional data series.

With regard to intense rainfall, the system classifies 2,120 mountain and hilly catchment areas according to their risk of flash flooding. Of these, 367 are at very high risk and 539 at high risk.⁸⁵ The classification is based on the topographical and surface characteristics of the catchment areas; it is therefore a slowly changing layer. It indicates where the increase in intense rainfall described in Section III.4 may cause flash floods. The classification indicates the hazard and exposure; however, the damage caused by flash floods is not quantified, as public damage statistics do not provide a breakdown by hazard type (V.2).

IV

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Exposure and vulnerability – the two forgotten factors of risk

KEY FINDINGS

Well-established trend, domestic figures	According to domestic data, heatwaves resulted in an average of 814 excess deaths per year between 2011 and 2023, with extremes ranging from 28 to 1,741.
New findings – international literature and domestic measurements	Deaths attributed to heat are almost entirely concentrated among those aged 75 and over, and the heat burden on this age group in 2021–2025 is 3.2 times that of the 1991–2020 period.
Institutional gap	Official vulnerability data are based on the period 2005–2014, while the population projection is based on 2011 figures.

IV.1 Human health

The health impacts of heat are the best-documented vulnerability chain in Hungary, and this section includes one of the figures in the analysis that is derived from a peer-reviewed domestic publication rather than from our own calculations. **Between 2011 and 2023, the average annual excess mortality nationwide is 814 people, with extreme values ranging from 28 to 1,741.**⁸⁶ During heatwaves, excess mortality of between 11 and 35 per cent is recorded across Europe, despite the warning systems in place. The national heatwave warning system was developed in 2005, and since then it has been necessary to issue it between one and five times a year.

This figure is open to misinterpretation in two respects. The first concerns the quantity. Excess mortality (all causes) and mortality attributed to heat are two different quantities; the figure above relates to the former and therefore cannot be directly compared with attribution estimates. The other is the source: as the cited publication is of a summary nature, the figure originates from the database cited therein, the primary methodological description of which must be obtained separately if we wish to cite the methodology as well.

However, a preliminary result has been received from the summer of 2026, which we are publishing here for information purposes only. The mortality data, designated as preliminary by the data provider, did not reveal any significant excess mortality during the record-breaking heat-wave at the end of June. This is the least well-substantiated quantitative claim in this analysis; it is therefore presented here as a qualitative indication, and the question remains open until the primary, updated time series is obtained. The two errors are not symmetrical – an erroneous conclusion that ‘there was no excess mortality’ would justify scaling back preparedness measures – and so we do not draw any planning conclusions from this.⁸⁷

The two findings are compatible, but must be read in conjunction with one another. If the preliminary result is confirmed by the primary time series, it allows for three possible explanations, none of which can be ruled out:

- 1 Adaptation is working** – the heat alert system, the spread of air conditioning and public awareness have reduced the impact.
- 2 The indicator is insensitive** – excess mortality is a crude measure, so only large deviations are visible in it, while smaller, real effects may remain hidden.
- 3 The nature of the event was different** – it was shorter, occurred at a different time of year, or had a course that affected vulnerable groups to a lesser extent.

A German study provides an important caveat regarding the first explanation. Huber and colleagues (2025), analysing data from the 15 most populous German cities for the period 1993–2022, found that heat-related excess mortality had decreased in most cities, even though summers had become warmer. The reason for this was a decline in heat sensitivity, which went hand in hand with an increase in life expectancy. Had life expectancy not improved, climate change would have caused an upward

trend. Meanwhile, the proportion of heat-related excess mortality attributable to climate change increased by 5.6 percentage points per decade (95 per cent uncertainty interval: 2.6–8.6), and averaged 53.6 per cent over the period studied.⁸⁸ A declining or stagnating mortality rate therefore does not indicate a weakening of the climatic effect, as this may be masked by non-climatic improvements. The situation in Hungary may differ from that in Germany in two respects: the trend in life expectancy is different, and the heat exposure of those aged 75 and over in 2021–2025 is 3.2 times the 1991–2020 level (IV.2), which acts in the opposite direction to the masking effect.

A European study published in October 2026 provides the first estimates for Hungarian cities regarding the proportion of heat-related deaths attributable to warming caused by human activity. Barnes and colleagues modelled the summers of 854 European cities between 2000 and 2025, including those Hungarian cities in which around 29 per cent of the country's population lives.²⁴⁷ In these cities, an average of around 390 deaths per year are attributable to heat, 56 per cent of which (37–72) are the result of human-induced warming, a figure close to the German figure of 53.6 per cent mentioned above. In Budapest in 2025, the estimate is 210 heat-related deaths, more than in 2003, and 76 per cent of these are attributable to global warming. On average across Europe, this proportion rose from 39 per cent to 68 per cent between 2000 and 2025. The estimate is based on a model calculation which provides a burden calculated from temperature rather than observed deaths. It assumes a constant relationship between temperature and mortality, thus disregarding the adaptation described above; according to the authors, it tends to underestimate the absolute burden. The trend for Budapest in 2025 differs from that indicated by the national weekly mortality data for 2025 (see below); however, there is currently a lack of domestic data to determine the cause of this discrepancy. The absolute figures in the study relate to the urban sample, i.e. a different population to that covered by the national estimates above.

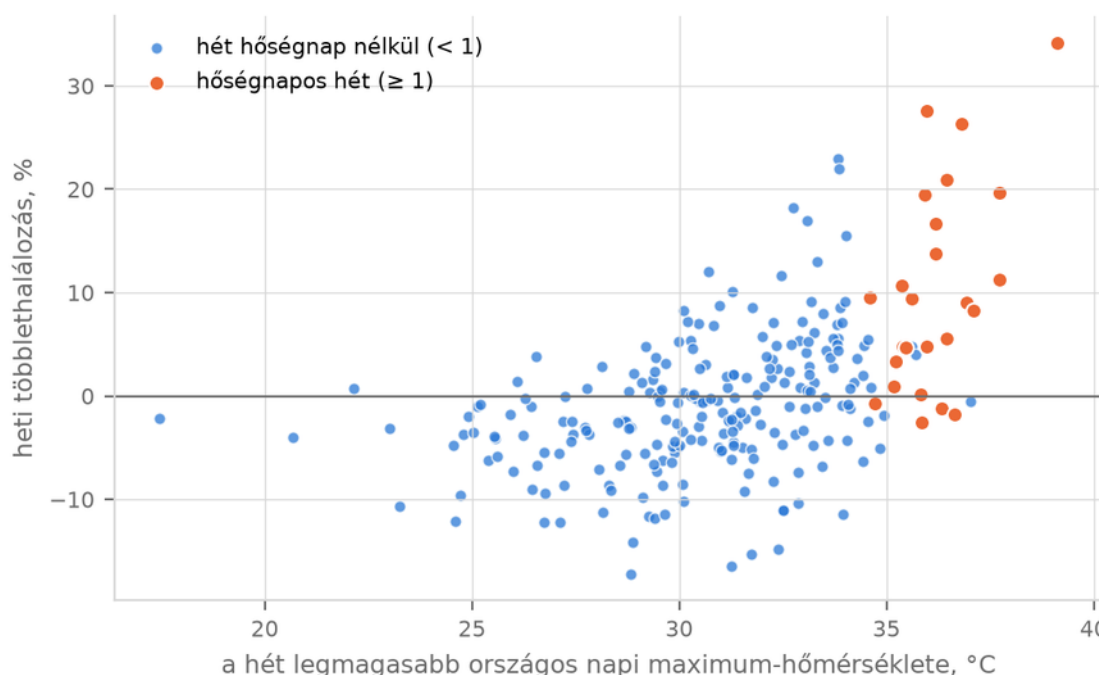
The planning conclusion is that the relationship between heat and mortality is not a mechanical function of temperature – this is also evident in the peer-reviewed domestic data series, where annual excess mortality varies between 28 and 1,741 people. If adaptation matters, this is both good news and a warning, because dismantling the protection system would have immediate repercussions. The appropriate indicator is not the record temperature, but the cumulative number of days above the threshold and the availability of real-time mortality data.

The calculation below is based on Eurostat's weekly mortality time series – that is, the preliminary release of the primary time series mentioned above, in which the weeks for 2025 and 2026 remain provisional. A comparison of the time series with the national temperature grid provides numerical support for the picture outlined above.⁸⁹ During the summers between 2005 and 2025, excluding the pandemic years (2020–2022), there is a moderately strong correlation between weekly excess mortality and the week's highest national daily maximum temperature (Spearman's $\rho = 0.52$; Figure IV/1). In weeks in which there was at least one extremely hot day on a national average, mortality was on average **10 per cent** higher than in the corresponding week of previous years, amounting to approximately 230 additional cases per week, while no excess was observed in summer weeks without extremely hot days. The effect is therefore measurable and is linked to weeks with extremely hot days.

However, there is considerable variation from year to year. The excess in weeks with extremely hot days stood at around 1,400 in 2015 and around 1,450 in 2024, while in 2025 it was practically zero, despite five weeks with extremely hot days. At the end of June 2026, during the week of the record-breaking heatwave, preliminary data show a 5–6 per cent increase, roughly half the average for weeks with extremely hot days. The figures for both 2025 and 2026 are preliminary, and may be revised upwards as data are received later. If the two low figures are confirmed in the final data, this would tip the balance towards 'adaptation' and 'event structure' among the three explanations given above; in the meantime, the two years taken together show that the impact of heat on mortality varies significantly from year to year. The two errors are not symmetrical here either. An unfounded interpretation that 'the effect has passed' would justify scaling back preparedness measures; therefore, we do not draw any planning conclusions from this data either. An independent analysis of KSH data up to 30 August found no detectable excess mortality during the second summer heatwave (29 July – 17 August). It names late-arriving data and adaptation as possible reasons, and also that the first heatwave brought forward the deaths of some of the most vulnerable: the shortfall that followed, the mortality trough, may have been filled by the excess of the second wave, which is why no excess shows in the weekly data. According to the analysis, this cannot be quantified from the available data.²⁴⁹

FIGURE IV/1

Weekly excess mortality rises in tandem with the week's highest temperature; weeks with extremely hot days are mostly on the 'excess' side.



Summer weeks (calendar weeks 22–35, roughly June–August), 2005–2025, excluding the years 2020–2022; excess relative to the median for the same week in the previous five years, %.

SOURCE Own calculations based on Eurostat's weekly mortality time series and HungaroMet's homogenised daily grid.

NOTE Orange dot: a week with at least one extremely hot day in the national average. Excess mortality from all causes, not deaths attributed to the heat. Data for the weeks in 2025 are preliminary.

The third source measures a different quantity using a different method. The ISGlobal research institute in Barcelona and its partners (Janoš et al., 2025) use a statistical model based on European weekly mortality data and daily temperatures to estimate how many deaths can be attributed to heat between 1 June and 30 September. For Hungary, the estimate gives 1,013 heat-related deaths for 2022, 555 for 2023 and 1,443 for 2024, representing 105, 58 and 150 cases per million inhabitants respectively; the 95 per cent uncertainty interval is wide in all three years (ranging from 138 to 2,542 in 2024).⁹⁰ This estimate represents a different measure from the excess mortality figures given above. The former counts the observed excess on heat-alert days, the latter the modelled heat effect over the entire summer, including moderately warm days; therefore, the two figures cannot be compared or added together.

The estimate has also been prepared by age group, and the picture is clearest in this breakdown. Among those aged 75 and over, heat-attributed deaths per million population were 1,158 in 2022, 629 in 2023 and

1,668 in 2024. Among those aged 0–74, the figures were 15, 7 and 19 respectively, with the margin of uncertainty including zero in all three years. The burden of heat-related deaths therefore falls almost entirely on the oldest age group. In 2024, the rate for those aged 75 and over is nearly ninety times that of the younger age group. Estimates for the two age groups were calculated separately; consequently, their sum does not equal the national figure, and their ratio cannot be interpreted as the distribution of deaths.

This is what gives the heat-burden indicator its weight. The heat burden measured for those aged 75 and over on extremely hot days in 2021–2025 is 3.2 times the 1991–2020 level (IV.2), and according to the above estimate, it is precisely this age group that bears the lion's share of heat-related mortality. Two gaps limit the picture: the domestic series, based on days with heat alerts, ends in 2023, and no source provides a national estimate for 2025.

The Hungarian Central Statistical Office's (KSH) daily mortality series, on which our own calculations are based, provides a more accurate picture than the weekly data.⁹¹ The Demographic Yearbook publishes national mortality figures for every day between 2011 and 2024. We compared this with the daily national average temperature from the national homogenised grid, excluding the pandemic years (2020–2022). The method used is the distributed lag model, widely employed in examining the relationship between heat and mortality, which tracks the effect of temperature for 21 days following a hot day (Figure IV/2). The analysis plan was established prior to running the model, and the results were replicated in an independent re-analysis using a different model family based on the raw data (G.6).

Three findings emerge:

The first finding concerns the timing. The effect of the heat on mortality is immediate, not weeks later; the excess mortality is highest on the hot day itself and subsides within four to five days.

The second finding concerns mortality displacement (deaths brought forward). In theory, a short-term excess could simply represent deaths brought forward by a few days: those of people who would have died soon anyway, even without the heat. A sign of this is a mortality deficit in the days following the excess, and this is indeed visible to a small extent in the Hungarian data. However, only around a quarter to a third of the short-term excess mortality associated with the hottest days – the hottest 1 per cent of days, with a national daily mean temperature of around 27

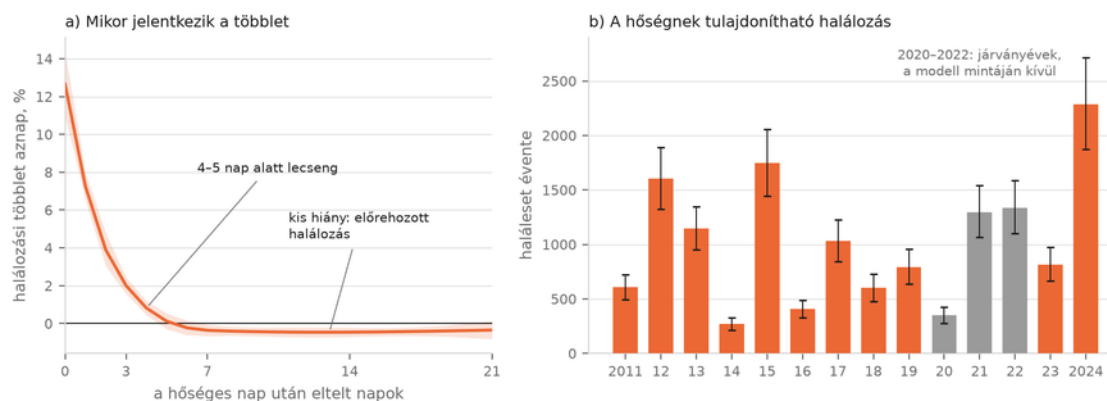
°C – is offset within three weeks; the remainder represents a loss of life lasting at least three weeks. According to the international literature, the majority of deaths attributed to heat in daily analyses shorten life expectancy by at least one year.⁹²

The third finding concerns the order of magnitude. Summarising the 21-day effect between 2011 and 2024, excluding epidemic years, an average of around 1,000 deaths per year can be attributed to heat. The highest figure is for 2024: around 2,300 deaths (95 per cent uncertainty interval: 1,900–2,700). This is followed by 2015 and 2012. Between 10 and 25 July 2024, of the approximately 6,100 deaths recorded over the 16 days, the model suggests that around 1,060 can be attributed to the heatwave. In the same year, official cause-of-death statistics recorded 27 cases as heat-related deaths.⁹³ The two figures represent different quantities; therefore, their ratio is not a measured value, but the order of magnitude clearly shows that the vast majority of heat-related deaths do not appear as heat-related deaths but are classified under other causes of death. The impact of the heat on mortality is thus immediate but remains hidden in the cause-of-death statistics.

This figure differs from the above-mentioned excess mortality of 814 people and cannot be added to it. The former measures the observed excess on alert days; this one measures the modelled effect of every day with a national daily mean temperature above 21.9 °C, including moderately warm days below the alert threshold. It belongs to the same family as the ISGlobal estimate, but differs from it in that this one is calculated from daily data and for the whole year, whereas that one uses weekly data and the June–September period. For 2024, the uncertainty intervals of the two estimates overlap. The result is valid subject to three caveats. The national average temperature does not account for regional differences. The daily data are all-cause, as cause-specific daily mortality data are not publicly available. The estimate of the displaced (brought-forward) fraction is sensitive to how the time trend is handled; therefore, it is presented as a range.

FIGURE IV/2

The effect of heat on mortality is immediate, and the greater part is not merely displaced (brought-forward) mortality; in 2024, approximately 2,300 deaths can be attributed to the heat.



a) The excess mortality on a day-to-day basis following a day falling within the hottest 1 per cent of days (27.2 °C national daily mean temperature), compared with the minimum mortality level at 21.9 °C. b) Deaths attributable to the heat, on an annual basis, with a 21-day lag, 2011–2024.

SOURCE Own calculations based on the daily mortality table from the Hungarian Central Statistical Office's Demographic Yearbook and HungaroMet's homogenised daily grid.

NOTE Interval and margin of error: 95 per cent confidence interval. The years 2020–2022 (grey) fall outside the model's sample and are provided for information purposes only. Deaths attributed to heat are model estimates, not observed excess mortality.

Two further European studies provide Hungarian figures, on a different question. Beck et al. (2026) used event attribution to analyse the summer of 2022, specifically to determine to what extent human-induced warming made heat-related deaths more likely during that period. In Hungarian regions, the probability of a heat-related mortality event similar to that of 2022 increased by a factor of 1.9–4.4 compared with the pre-industrial climate; the median for Hungarian regions was 3.0, while that for European regions was 3.4, which is slightly below the European average; in Southern Europe, however, the same multiplier averages 26.5.⁹⁴ During the week with the highest number of deaths in the summer of 2022, 4.4–7.6 per cent of deaths in Hungarian regions were attributable to the heat. The proportion was highest in the Northern and Southern Great Plain, at 7.6 and 7.1 per cent respectively, and lowest in Central and Western Transdanubia, at 4.4 and 4.5 per cent. Wu and colleagues (2025) project future trends, assuming no adaptation and maintaining the 2010–2019 level of adaptation. According to their findings, in Hungary, heat-attributable mortality could amount to 146 cases per million inhabitants per year at 1.5 °C of global warming and 1,105 at 4 °C, and the study ranks Hungary among the emerging European hotspots.⁹⁵ None of these figures can be directly compared with the domestic and ISGlobal figures

mentioned above, as they relate to different quantities, different time periods and different methodologies.

Beyond mortality: morbidity, healthcare system, target groups

Mortality is only the most easily measurable aspect of the health burden of heat. The only nationwide, peer-reviewed domestic study on morbidity, based on emergency care data for a random half of the population (3.52 million cases, 2009–2017), found that a day with a daily mean temperature above 25 °C increases the number of emergency cases by 1.6 per cent over the following eleven days, while a heatwave day increases it by 2.0 per cent. Warming relative to 1950–1989 levels resulted in approximately 46,800 excess cases between 2009 and 2017 (95 per cent confidence interval: 39,300–54,200). The impact is 30–35 per cent greater in low-income districts and 35–50 per cent greater in districts with a shortage of GPs.⁹⁶ This is vulnerability data, showing that heat places the greatest strain on the healthcare system where primary care is weakest. The data series ends in 2017, and time series on hospital admissions and ambulance service call-outs during heatwaves are not publicly available (Annex F); consequently, no one is currently monitoring the strain on the healthcare system caused by heatwaves on an ongoing basis.

International literature and domestic institutional surveys identify four groups for whom the mortality rate alone is not a sufficient indicator:

- **The elderly.** They bear the lion's share of the mortality burden (see above). 88 per cent of social care homes had no air-conditioned rooms, and 33.6 per cent had a heatwave plan (2019 survey).⁹⁷
- **People with chronic conditions and those receiving inpatient care.** Among elderly patients taking diuretics, beta-blockers or antipsychotics, hospital admissions due to heat are 21–33 per cent higher during heatwaves (US data).⁹⁸
- **Pregnant women and young children.** Even a short heatwave immediately increases the risk of preterm birth and adverse effects in infancy: during a heatwave, the likelihood of preterm birth is 16 per cent higher (a meta-analysis of 70 studies). Prolonged exposure to heat during pregnancy and early childhood is associated with slowed growth and delayed maturation of white matter.⁹⁹ 79 per cent of crèches and 72 per cent of kindergartens did not have air-conditioned rooms.⁹⁷
- **Outdoor workers.** The number of workplace injuries increases by 1 per cent for each degree of temperature rise and by 17.4 per cent during a heatwave (international meta-analysis).¹⁰⁰ Domestic health and safety

regulations set out obligations relating to heat, but there are no domestic statistics on work-related accidents linked to heat.

We discuss the four groups separately because illness, workplace accidents and adverse pregnancy outcomes affect more people than deaths, and there is no domestic monitoring of any of them. The health burden of heat is therefore greater than the above mortality figures suggest, but it is not currently possible to estimate by how much based on domestic data. This is our own conclusion; it is not supported by any domestic estimates.

IV.2 Vulnerability data are out of date

Here comes the most uncomfortable institutional finding of the analysis. The official national adaptation geoinformation system contains a heat-wave vulnerability layer – showing the daily excess mortality per one-degree increase, broken down by micro-region and county. This is precisely the kind of data that risk analysis requires. **However, its time frame covers 2005–2014**, meaning it ended more than a decade ago. The climate layer of this same system is based on the previous generation of models (CMIP5-era regional models), with time windows covering 2021–2050 and 2071–2100, and three different reference periods, none of which matches those used by the more recent official products.¹⁰¹

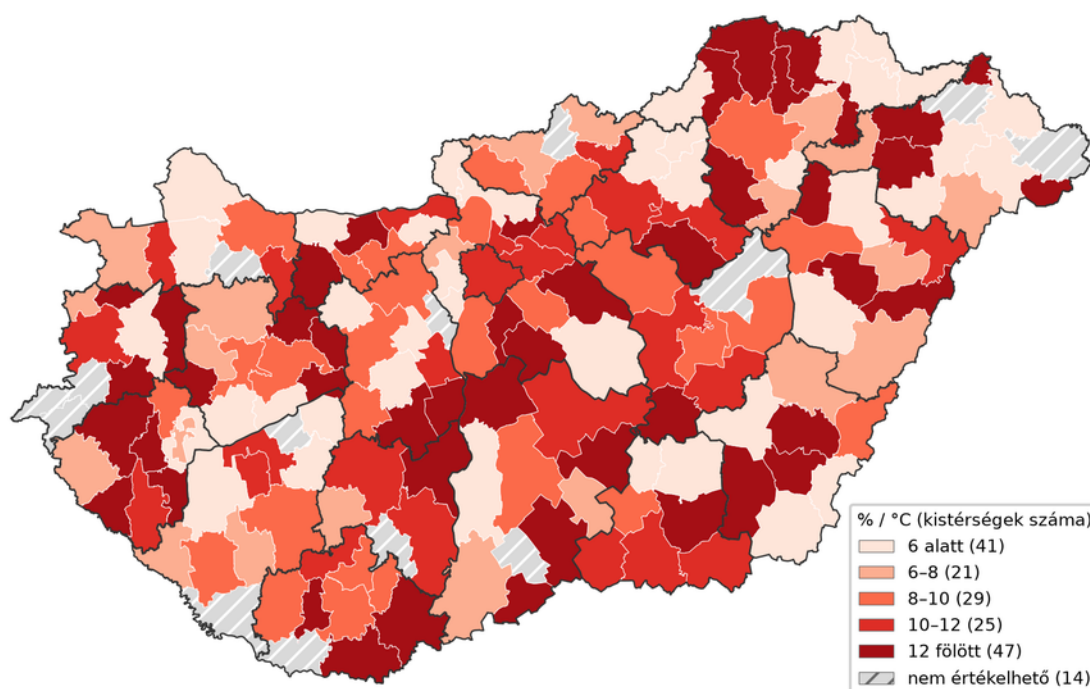
The obsolescence is evident. According to the study underpinning the system, the national annual excess mortality attributable to heat was approximately 780 cases in the 2005–2014 period, rising to roughly 2,000 for 2021–2050, and to an average of 5,800 for the period 2071–2100 – **assuming unchanged vulnerability and an unchanged population. It is precisely this assumption that is the weak point, as the heatwave warning system has been in operation since 2005**, air conditioning has become more widespread, and public awareness has increased – vulnerability has therefore presumably shifted since the end of the measurement period, though we do not know by how much. The vulnerability layer, based on a window that closed a decade ago, is thus not merely outdated, but also uncertain in terms of today's risk, as it is impossible to know whether it is an overestimate or an underestimate.

The system's observation layer provides even more information, and this part becomes obsolete more slowly (Map IV/3). In the 2005–2014 window, the threshold temperature for heatwave days ranges from 22.3 to 25.4 °C across sub-regions.¹⁰² The median daily excess mortality per 1 °C increase in temperature across the 163 assessable sub-regions is 9.5 per

cent, while the middle 80 per cent of sub-regions show a range between 2.9 and 16.2 per cent. **Much of this variation stems from small sample sizes; therefore, the layer itself specifies a reliability category:** of the layer's 177 micro-regions, 98 are classified as high reliability, 56 as medium reliability, 9 as indicative, and 14 as unassessable. For planning purposes, therefore, the county level is more reliable, where the range is between 5.5 and 11.2 per cent, with the highest value recorded in Budapest.

MAP IV/3

The impact of heat on mortality varies greatly between micro-regions, and cannot be assessed in fourteen micro-regions.



Daily excess mortality per 1 °C increase in temperature, %, 2005–2014; the legend indicates the number of micro-regions.

SOURCE Layer from the National Adaptation Geoinformation System; the map was compiled in-house from the raw layer retrieved.

NOTE Some of the sub-regional values are based on a small number of cases; according to the layer's own reliability category, 98 sub-regions are classified as having high reliability and 56 as having medium reliability.

So while we update the hazard side annually, the other two risk factors – exposure and vulnerability – have not been updated for a decade. The same pattern emerges as with model conservatism, only in relation to the other factor – though in this case, the fix is cheaper, as it requires data updates rather than model development.

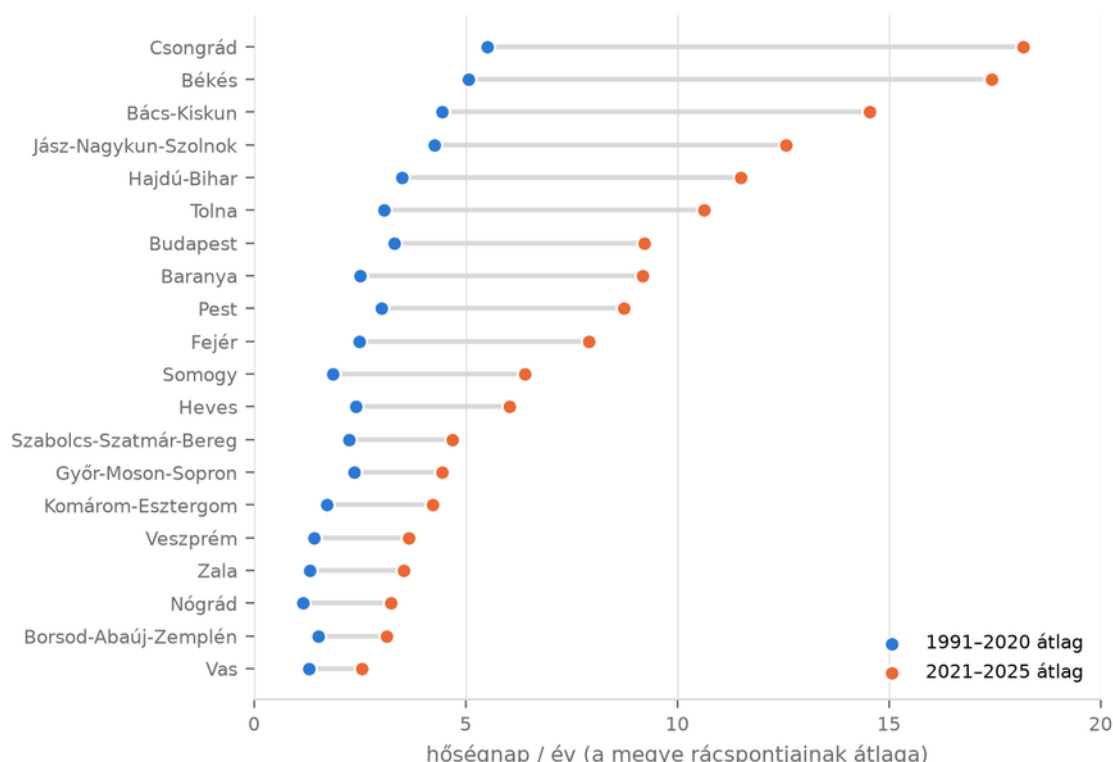
The exposure side has been updated in this edition.¹⁰³ The number of people aged 65 and over rose from 1.68 million in the 2011 census to 1.96 million by early 2022 (+17 per cent), while the number of those aged 75

and over rose from 730,000 to 795,000 (+9 per cent); the number of households consisting solely of people aged 65 and over rose from 814,000 to 907,000. The hazard side has changed much more rapidly: the county-average number of extremely hot days (daily maximum $\geq 35^{\circ}\text{C}$) rose between the 1991–2020 and 2021–2025 periods from 5.5 to 18.2 in Csongrád-Csanád, in Békés from 5.1 to 17.4, and in Bács-Kiskun from 4.4 to 14.5, while the increase was much smaller in the western and northern counties (Figure IV/4).

The product of these two figures – the exposure of those aged 75 and over on extremely hot days (person-extremely hot days) – rose from 2.1 million to 6.8 million, a 3.2-fold increase. The population figures are taken from the 2011 census and the population data for 1 January 2022 (Eurostat), while the number of extremely hot days is based on the two periods. Breaking down the increase mathematically, 88 per cent is attributable to the rise in the hazard, 4 per cent to population ageing, and the remainder to the combined effect of the two. This cannot be interpreted as a causal relationship, and the five-year period is significantly skewed upwards by the extreme summer of 2024. However, the trend clearly shows that heat stress has increased more rapidly than assumed by the 2005–2014 vulnerability layer, and that this increase is driven primarily by heat, not by demographics. An update of the vulnerability layer (excess mortality per one-degree increase) remains outstanding.

FIGURE IV/4

The number of extremely hot days has increased in every county, most markedly in the southern and eastern parts of the Great Plain.



Extremely hot days (daily maximum $\geq 35^\circ\text{C}$), days/year, average of the county's grid points; blue: 1991–2020, orange: 2021–2025.

SOURCE Own calculations based on HungaroMet's homogenised daily grid; county boundaries: Eurostat GISCO NUTS 2021.

NOTE The five-year period is significantly skewed upwards by the extreme summer of 2024; the difference is a period-specific value, not a trend.

The urban heat island

The county average masks the differences within the city. According to the HungaroMet KLIMADAT 2.0 layers for Budapest's districts and Szeged, the heat island is primarily a nocturnal phenomenon. The number of tropical nights (where the daily minimum remains above 20°C) between 1996 and 2025 was 2.8 per year on a national average, 8.0 across Budapest as a whole, 20–21 in the inner Pest districts (V, VI), 4.0–4.3 in the hilly Buda districts (II, XII), and 6.6 in Szeged. The difference in the number of days reaching 30°C is smaller: 31.4 nationally, between 21.7 and 35.2 in the districts of Budapest, and 43.7 in Szeged.¹⁰⁴ This layer is not a direct measurement, but the sum of the homogenised grid and the thermal island calculated using the SURFEX surface model (H.2); therefore, the exact values are model-dependent, while the order of magnitude and spatial pattern of the night-time difference are more reliable.

Station measurements confirm the modelled picture and show the difference to be greater. At the inner-city station in Szeged, there were an average of 31 tropical nights per year between 2016 and 2025, and 9 at the outlying station; by 9 October 2026, the figures were 41 and 18 respectively. Between 2002 and 2025, the average summer night-time minimum in the inner city was 2.8 °C higher than in the outskirts, and on days when the temperature reached 30 °C, it was 3.4 °C higher. In Budapest, the inner-city (District II), Lágymányos (District XI) and Állatkert (District XIV) stations recorded 28, 39 and 44 tropical nights per year respectively between 2016 and 2025, while the suburban station at Pestszentlőrinc recorded 15; whereas at the Újpest station there were only 8, which may be due to the influence of the station's surroundings. During the day, the picture is reversed: the number of days reaching 30 °C is higher in the outlying areas; in Szeged, there were 57 such days per year between 2016 and 2025, compared with 47 in the city centre.¹⁰⁵ The modelled district-level layer yields fewer tropical nights than the measured station values: 4 for District II compared with the measured 28, and 9 for District XI compared with the measured 39. This is partly due to the fact that the layer represents a district average, while the station is a single point, and the time periods are not identical. However, given the magnitude of the difference, we consider the modelled heat island to be rather a lower-bound estimate.

Of the three factors – hazard, exposure and vulnerability – this data describes exposure. According to a European study, one of the main drivers of future heat-related deaths will be the combined occurrence of daytime and night-time heat,⁹⁵ and it is precisely the night-time cooling that is lacking in the inner districts. The heat stress calculation above, which is based on grid averages, does not take this into account; consequently, it is likely to underestimate the stress in densely built-up urban areas, although this has not yet been confirmed by measurements.

IV.3 Agriculture

A defining feature of this exposure is that Hungarian agriculture is forced to cope **simultaneously** with winter cold, spring frosts and summer heat and drought. The challenge therefore cannot be addressed solely by using heat-tolerant varieties – the range of extremes is widening, not simply shifting.

The rapid attribution analysis also provides domestic figures on the yield implications of the summer of 2026: 4–4.4 t/ha for wheat instead of the

usual 5–5.5, and around 4.3 t/ha for winter barley.⁸¹ According to the AKI's August summary, the national average yield for winter wheat was 4.3 t/ha, 22.7 per cent lower than in 2025, with a total harvest of 4.2 million tonnes.²⁴⁸ It is important to note that these are reported impacts, not attributed domestic probabilities – the authors explicitly state this, and confusing the two constitutes a separate type of error. Regarding the €2.4 billion domestic crop loss attributable to the 2022 drought, the authors of the source themselves state that this accounted for approximately 1.4 per cent of annual gross domestic product in Hungary and Romania. This proportion is derived from the authors' figures, not from our own calculations.¹⁰⁶

There are not only quantitative but also qualitative limits to the expansion of irrigation. The area at risk of secondary salinisation covers some 400,000 hectares, the majority of which is in the Great Plain. The risk arises in two ways: through irrigation water with a high salt content and through rising saline groundwater. The risks associated with well-water-based irrigation vary from region to region, as does the chemistry of the groundwater: in the Tiszántúl region and the Danube Valley, it is typically sodium bicarbonate-rich – and therefore salinising – while on the sandy soils between the Danube and the Tisza, it tends to be calcium bicarbonate-rich. The process does not reverse of its own accord, as the sodium bound to soil colloids remains there even after the water table has fallen, and the soil becomes compacted and less permeable, and thus more susceptible to drought. The literature is ambivalent in that, with appropriate water quality and water management, irrigation can also have a leaching effect. We know all this from secondary sources, prior to primary verification; it should therefore be treated as an order of magnitude rather than a threshold value. With regard to point IX.3, it nevertheless clearly follows from this that compliance with water quality standards is included amongst the conditions for the expansion of irrigation.

The section on insurance and damage mitigation is the least developed part of the analysis. The breakdown of damage mitigation payments by type of risk is available from 2012 onwards from the AKI's annual assessments. The total amount of compensation between 2012 and 2024 was 162.8 billion forints, of which 70.4 per cent was for drought damage and 13.9 per cent for spring frost damage; excluding the drought years of 2022 and 2024, these figures were 48.1 per cent and 24.9 per cent respectively.¹⁰⁷ The payout is not the same as the loss, but rather compensation filtered through eligibility rules and redistribution. In the 2022

loss mitigation year, for example, only 80 per cent of valid claims were paid out.¹⁰⁸ We do not provide figures for the insurers' breakdown by type of hazard.

A review of the literature on major domestic crop yields

So far, we have not linked two issues: the depletion of groundwater reserves (III.1) and the cost of this in terms of crop yields. Peer-reviewed Hungarian literature has already examined this relationship, and three of its findings relate directly to this question.

The relationship between groundwater level and maize yield is measurable and quantifiable. According to a study of 283 wells covering the period from 1961 to 2010, the twenty-five-year average of shallow groundwater levels was lower in the second window than in the first, in every region and in every month of the year. The national average decline across the wells studied was 2.24 cm per year. For maize yield, the water level in August–October shows the strongest correlation: in the Great Plain, it accounts for around one-third of the inter-annual variation in yield, and according to the model, a one-metre higher water level would result in a yield increase of 2.33 t/ha. The economic significance of this relationship is diminished by the decline in the area under maize: the area under maize harvest fell from an average of 1.10 million hectares in 2010–2019 to 0.85 million hectares (–23 per cent) for 2021–2025, and to 0.74 million hectares in 2025. This has been partly replaced by sunflowers (+78,000 hectares, +13 per cent); the areas under wheat and rapeseed have also decreased, while the fate of the remaining area is not shown in the Hungarian Central Statistical Office's (KSH) crop-specific tables (KSH STADAT Tables 19.1.1.12 and 19.1.2.11). In drought years, the harvested area does not include sown land from which no crop was harvested; therefore, part of the decrease is due to the effects of drought rather than a change in the cropping structure. In the Great Plain, the estimated cost of a 0.28-metre drop in water levels between two measurement windows in August–October is 0.65 t/ha per annum, which represents 11.6 per cent of the average yield for the period.¹⁰⁹ **Three caveats apply. For wheat, the relationship is weak. The authors attribute this to wheat's deep root system, as the roots reach close to the water table for much of the growing season, and this direct connection is presumably unaffected by regional water level fluctuations. The result is therefore crop-specific, not generalisable. The study measures statistical correlation, not causal mechanisms, and does not break down how much of the decline is due to climate and how much to abstraction. There is even a discrepancy within the pa-**

per itself: the summary puts the explained proportion between 18 and 38 per cent, while the discussion section puts it between 10 and 38 per cent. The upper limit is the same in both places, but the lower limit is not.

This same study also supports our retention recommendation, and does so directly. According to the data cited in the report, the 42,600-kilometre inland water drainage network diverts an average of 1.77 billion cubic metres of water annually from drought-prone plains, and it does so not only during periods of flooding. The proposed retention site is a former floodplain of poor agricultural quality, which accounts for nearly a quarter of the Great Plain. This constitutes independent, peer-reviewed evidence supporting the retention provision in point [IX.2](#).

Rising yields do not refute the climate risk, as the two address different issues. According to a study spanning ninety years, three non-overlapping thirty-year periods and four bioclimatic regions, the average regional wheat and maize yields in the 1981–2010 period were 3.3 times and 3.2 times higher, respectively, than between 1921 and 1950. The authors attribute this increase predominantly to advances in agricultural technology. Yield variability, however, is increasingly climate-driven; between 1981 and 2010, rising average temperatures and declining rainfall together accounted for 46–75 per cent of the variance in maize yields. In the first two periods, between 1921 and 1980, temperature indices showed no explanatory power at all for maize yields.¹¹⁰ Without distinguishing between the two, the yield data can be misleading – and is regularly misinterpreted in the domestic debate.

Two further findings from the same study are important from a planning perspective. (1) Spatial reorganisation: the sensitivity of wheat yield to summer temperature has shifted over the course of the century from the cooler hills to the plains, and by 1981–2010 the average wheat yield in the Great Plain had become the lowest of the four regions. (2) **A contrasting finding, and one that therefore warrants special mention, is that the rise in average January–March temperatures mitigated the yield-reducing effect of summer warming by 16–34 per cent during the same period – least of all in the Great Plain.** The picture is therefore two-sided. The results of the study should be treated with caution on two counts: it works with monthly averages, while a few days of extremes may account for more (this is the other side of the shortcoming mentioned in [H.4](#)), and the data series ends in 2010, so the 2022 drought is not included.

There is a domestic estimate of how much can actually be explained. The cross-validated explained variance of a statistical model run for four

crops between 2000 and 2016 was 67 per cent for wheat, 76 per cent for rapeseed, 81 per cent for maize and 68.5 per cent for sunflowers.¹¹¹ Two of the findings relate to other sections of the analysis. For wheat, a higher-than-usual vapour pressure deficit in May reduces yield – this is the yield-side counterpart to the increase in vapour pressure deficit shown in Section II.2, and had been missing until now. For maize, soil moisture in July and August is the decisive factor. This partly overlaps with the August–October window of the groundwater relationship mentioned above; the common month is August, and the two results are derived from two independent data sources. It should be noted that the seventeen-year window explains inter-annual variance, not a trend, and the two are not interchangeable.

This layer does not provide a damage assessment. The yield figures above are statistical and counterfactual estimates – calculations based on the difference between observed and modelled yields – and do not represent recorded losses; therefore, they do not make up for the shortfall described in Section V.1.

IV.4 The intersection of energy and water

In the summer of 2026, the water–energy chain turned from a theoretical risk into an operational incident. Due to record-low flows in the Danube and temperature regulations for discharged cooling water, the output of the Paks Nuclear Power Station had to be gradually reduced from 27 July. On 29 July, according to public statements, the power station shut down an entire unit for the first time in its history due to low flows. On 1 August, only two of the four units were generating electricity at reduced output, and total output fell to 476 MW. Reports differ regarding the most severe phase of the shutdown.¹¹² The water gauge at Vigadó Square in Budapest reached the 0 cm reference point on 9 September and fell below it (–1 cm) in mid-September. The low flows persisted into early October.¹¹³

The institutional side of the chain is the gap in responsibility. In the integrated environmental permit for the Tiszaújváros power station, the water management and water protection authority states that, due to the uncertain low-flow conditions, it makes no representation regarding a 100 per cent reliable water supply and therefore accepts no responsibility,¹¹⁴ while the supply-side planning treats the same capacity as guaranteed.

This is not an investment decision, but an operational one. The existing sensitivity analysis of the system design should include a **second condition**: low-flow output curtailment, with a frequency derived from the measured flow data. The summer of 2026 demonstrated that this is not a hypothetical assumption. Data on the exposure side of the chain is incomplete. There is no publicly available summary of the proportion of domestic generation capacity dependent on cooling water, nor of the impact of low-flow output curtailment on imports and prices; therefore, we do not quantify this.



Economic transmission

SECTIONS OF THIS CHAPTER

V.1	The missing national economic damage account	113
V.2	Known data and estimates	114
V.3	The discrepancy between the EU drought damage model and observations	116
V.4	Predictability of allocation	117

KEY FINDINGS

Institutional gap	There is no official national economic damage account; the only identified official macro-level estimate is sixteen years old.
New data	Between 1980 and 2024, losses from weather and climate extremes amounted to 12.8 billion euros, of which 4.8 per cent was insured.
New – domestic measurements	Maize is the most vulnerable major crop: yield losses exceeding 20 per cent all occurred during summers that were warmer than normal.

V.1 The missing national economic damage account

The most significant finding in this chapter is a **negative one**. There are no recent, official Hungarian macro-level estimates of the cost of inaction; the only such estimate identified is sixteen years old (150–180 billion forints per year).¹¹⁵ **In Hungary, stress tests are carried out, but no national economic damage assessment is conducted.** The only recent domestic macroeconomic model calculation identified was carried out for the purposes of stress tests: in 2021, Cambridge Econometrics, commissioned by the Hungarian National Bank, estimated the impact of climate change on the Hungarian economy.¹¹⁶ The estimate models the gradually intensifying physical impacts, primarily the decline in labour and agricultural productivity. According to this, by 2050 these will reduce GDP by 4.25 per cent on a 3.5–4 °C global warming scenario, and by around 1 per cent under the sub-2 °C scenario, compared with the baseline scenario that disregards climate impacts. The calculation does not include damage from extreme weather events and is based on a single temperature–productivity relationship estimated using interna-

tional data. This is a hypothetical scenario calculation, not a damage assessment, and therefore cannot be added to the figures in Section V.2. At sectoral level, the AKI publishes agricultural damage mitigation and insurance payments annually, broken down by district and type of risk; however, this measures compensation, not the total damage (IV.3).¹⁰⁷

It follows that public discourse in Hungary draws on figures that cannot be transferred geographically or conceptually. A telling example of this is the claim that ‘water scarcity could cost 7 per cent of GDP’; tracing the source chain reveals that the original estimate relates to water-stressed regions and measures a different quantity (ecosystem service risk value), and **is not supported by any Hungarian estimate**.¹¹⁷ The use of such a figure is persuasive in the short term, but undermines credibility in the longer term.

V.2 Known data and estimates

Where there is a valid Hungarian figure, we report it separately for each source and do not aggregate them, as they relate to different quantities (one-off event versus annualised expected value; producer revenue versus value added versus GDP; loss versus rate of loss increase versus coverage ratio).

The best Hungarian benchmark relates to the 2022 drought: the value of crop losses for six major arable crops in Hungary amounts to approximately **2.4 billion euros** – the second-largest figure in the region after Romania.¹⁰⁶ This figure should be treated with four caveats: pricing is skewed upwards by the peak prices of 2022; a loss in sales revenue is not the same as a loss of income, and even less so as a loss of GDP; this relates to a single year, not an annualised projected figure; finally, the weighting of the six crops reflects the 2022 crop mix, while the area harvested for maize has since decreased further.

The damage fluctuates significantly from year to year, so a trend cannot be established on the basis of a single bad year.

The series of losses published by the European Environment Agency, based on the CATDAT database, quantifies this fluctuation.¹¹⁸ In Hungary, between 1980 and 2024, the total losses from weather and climate extremes amounted to 12.8 billion euros at 2024 prices. Of this, 78 per cent occurred in just five years (1986, 2022, 1992, 1999, 2010); the median annual loss was 14 million euros, and only 4.8 per cent of the losses were insured. The figure of 2.5 billion euros for 2022 is of the same order of

magnitude as the crop loss estimate above, but was calculated using a different method; therefore, the two cannot be added together. The mortality data in this series is incomplete, as it records only a single death for all hazard types combined in 2024, while according to the weekly mortality data, the excess mortality in the weeks with extremely hot days that summer was approximately 1,450 cases (IV.1).

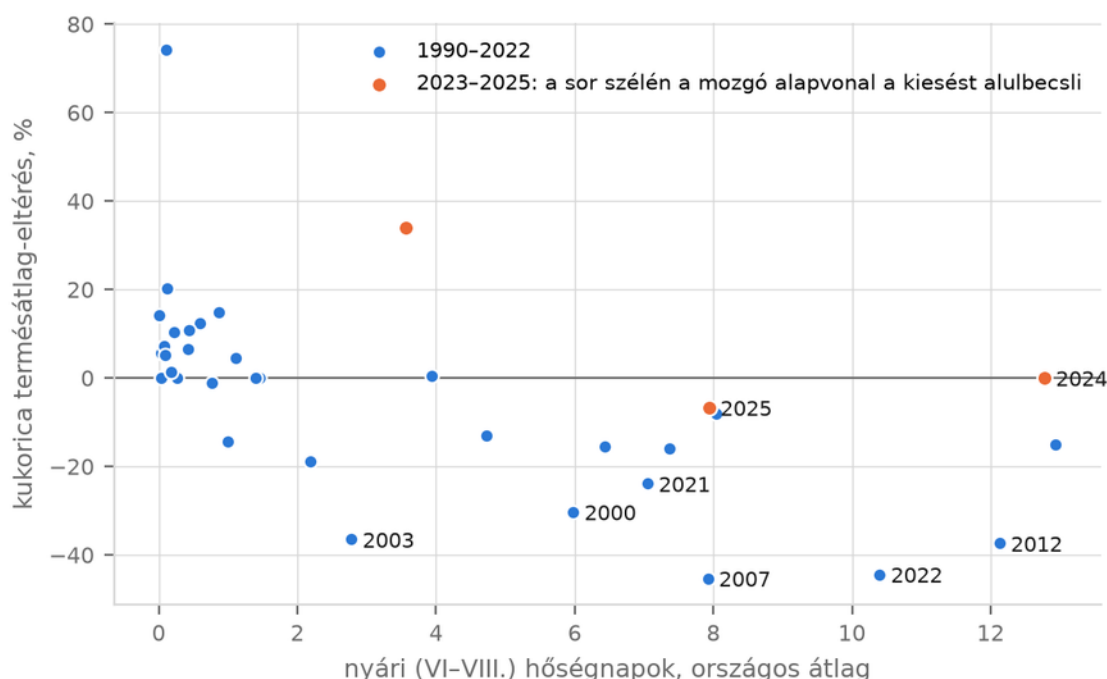
In agriculture, maize is the most sensitive major crop. The deviation of its average yield from the seven-year rolling median between 1990 and 2025 closely follows summer heat: the correlation with the number of extremely hot days in summer is $\rho = -0.68$, with the average summer maximum temperature at -0.65 , and with April–August precipitation at $+0.67$; by contrast, no such strong correlation can be demonstrated for wheat and sunflower yields (Figure V/1).¹¹⁹ In all six years in which maize yields fell by more than 20 per cent (2000, 2003, 2007, 2012, 2021, 2022), the average summer maximum temperature was at least 27.8 °C, which is above the 1991–2020 average of 27.4 °C; of these, the number of extremely hot days remained around the norm in 2003, while in the other years it was well above it. The calculation also gives rise to a methodological caveat. The moving baseline incorporates a series of poor years towards the end of the sequence, and therefore underestimates the shortfall in recent years. Compared with the fixed median for 2006–2020, the average maize yield between 2021 and 2025 fell short by an average of 15 per cent, and was below the median in four out of the five years.

The year 2026 adds to the end of the series a shortfall even more severe than that of 2022. At the time of writing, official data from the Hungarian Central Statistical Office (KSH) is not yet available; the preliminary figures are as follows. Maize was sown across 589,000 hectares; according to September estimates by the Ministry of Agriculture and the National Association of Cereal Growers, approximately 500,000 hectares of this can be harvested as grain, yielding around 3 tonnes per hectare, bringing the national harvest to approximately 1.5 million tonnes. This is below the 3.9 million tonnes recorded in 2025 and the 2.8 million tonnes in 2022, and would mark the lowest point in the national series published by the Hungarian Central Statistical Office (KSH) since 2000; domestic consumption stands at over 3 million tonnes, with the shortfall being made up by imports, and the country was already a net importer of maize in the first eight months. The preliminary national average of 3 tonnes is less than half the seven-year median for 2019–2025 (6.1 t/ha), meaning the yield falls below even the 2022 low of 3.4 t/ha (own calculations based on KSH data). Sunflowers were sown over a larger area than maize for

the first time (780,000 hectares); the average yield was around 1.6 t/ha, some 20 per cent lower than the five-year average. In Békés County, the county average for maize was 1.4 t/ha and for sunflowers 1.5 t/ha, and the county's maize area shrank from 95,000 hectares in 2004 to 34,000 hectares.²⁴⁸ These figures are provisional; they do not appear in the statistical analysis for 1990–2025 presented in this chapter, and they do not weaken the above correlations but rather reinforce them: the national average temperature in the summer of 2026 was the second highest since 1901 (II.2).

FIGURE V/1

Average maize yields are consistently lower during hot summers; the greatest shortfalls occurred during summers that were warmer than normal.



Deviation of average maize yield from the seven-year rolling median, %, by national average number of extremely hot days in summer (June–August), 1990–2025.

SOURCE Own calculations based on Table 19.1.1.18 of the KSH STADAT and the homogenised daily grid from HungaroMet.

NOTE Year labels: shortfall greater than 20 per cent, as well as 2024 and 2025. Orange dot (2023–2025): at the end of the series, the rolling baseline underestimates the shortfall; measured against the fixed median for 2006–2020, 2024: –12 per cent, 2025: –23 per cent.

V.3 The discrepancy between the EU drought damage model and observations

Standard EU drought damage modelling classifies Hungary in the regional group where it forecasts a **slight reduction in drought hazard** – with

the highest degree of uncertainty.¹²⁰ This **contradicts** the observed Carpathian–Balkan hotspot pattern and our own results.

All three interpretations must be noted. (1) According to one interpretation, the model’s conservatism is evident here too, and if we were to use this estimate as a benchmark for Hungary, we would be importing the very bias that this study was designed to document. (2) It cannot be ruled out that there is something in the continental average that the observed regional picture does not reveal. (3) A methodological explanation is also possible: European drying is not apparent in precipitation-based drought indices, but is evident in indices that also include evaporative demand – for the same continent and century, one family of indices shows drying while the other does not (II.2)⁶¹ – thus, the discrepancy between EU modelling and the observed picture may partly depend on which index family underlies the estimate. This is our own hypothesis, which we have not verified against the modelling documentation. We therefore treat the EU value as an order of magnitude rather than a Hungarian planning value.

V.4 Predictability of allocation

The central argument of the economic chapter is not about the magnitude of the damage, but rather that the risk lies in the distribution of water shortages, which economic planning does not take into account. The Water Management Act sets out the order of priority for meeting water demands; restrictions are imposed in the reverse order, and, with the exception of water use for subsistence purposes, are imposed without compensation.¹²¹ The order is therefore known, but capacity and investment planning has not been adjusted accordingly.

VI

The global picture and the domestic interpretation

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KEY FINDINGS

New – post-AR6 update	Global warming for the decade 2016–2025 is 1.26 °C; the rate of anthropogenic warming is 0.27 °C per decade, the highest on record.
New – post-AR6 literature	The Earth’s energy balance surplus has more than doubled over two decades; according to one study, models predict roughly half the 2023 value, while another suggests that observed values remain within the model range (VI.1).
Reading guide	The global picture does not calibrate the magnitude of domestic figures: it provides context, not evidence (VI.6).

The previous chapters have been based on domestic measurements. This chapter examines what the global picture adds to this, that is, in what direction and by how much the global-level background underlying the domestic figures has shifted since the completion of the IPCC’s Sixth Assessment Report. We do not dispute the report’s key findings. We examine what we know today that we did not know then, and what in this materially alters the Hungarian interpretation. The chapter approaches the subject from the perspective of measurements; thus, every statement is based on an observation, not a scenario.

The chapter relates to domestic figures at a single point, namely in the concluding Section VI.6. There, we summarise what aspects of the global picture alter the domestic interpretation and which do not – no domestic conclusions can be drawn from the intervening sections.

Global indicators **combine one-off step changes with sustained trends**; consequently, this chapter is most susceptible to over-interpretation. A regulatory change or an El Niño event causes a one-off step change in level, whereas carbon dioxide forcing results in a continuous rise. If the two were conflated, we would be counting the same warming twice. Where a step change is involved, we indicate this separately.

VI.1 Is the threat becoming more severe on a global scale?

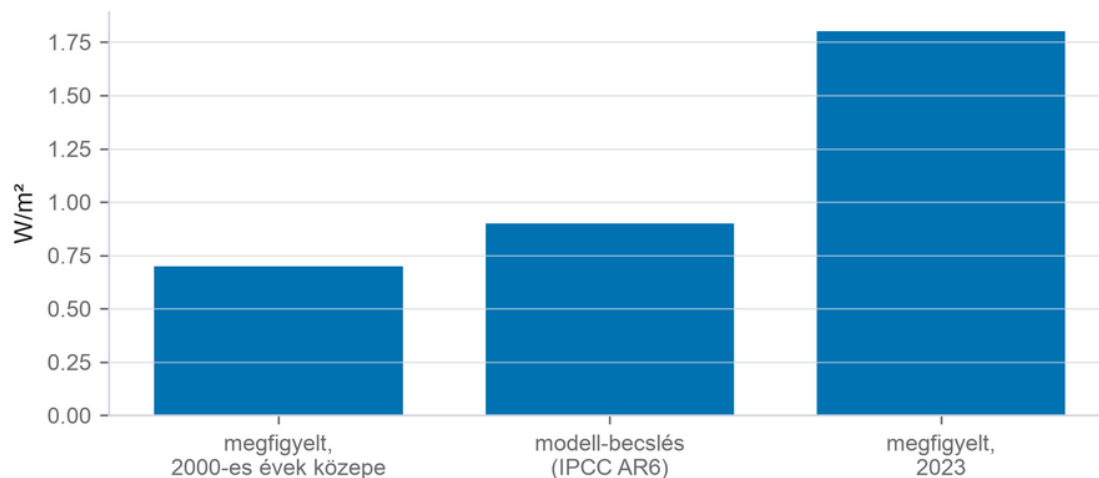
The temperature side can be read from an annually updated set of indicators.¹²² The observed warming for the decade 2016–2025, relative to the 1850–1900 baseline, is 1.26 [1.13–1.36] °C, of which 1.24 [1.0–1.5] °C is attributable to human activity. **For the year 2025 alone**, anthropogenic warming is 1.37 °C. The rate of anthropogenic warming over the past decade has been 0.27 [0.2–0.4] °C **per decade** – according to the authors of the dataset, this is the highest rate recorded in the instrumental record to date.

From a planning perspective, however, a more telling measure than temperature is the surplus in the Earth’s energy balance – that is, the net energy flux (W/m²) by which incoming solar radiation exceeds radiated heat, and which accumulates within the system. This determines ocean heat uptake, ice mass loss, sea-level rise and the amount of further warming already inherent in the system.

Since AR6, the greatest shift has occurred in this quantity. According to a paper by forty-four authors covering major modelling and observation centres, the energy balance surplus **has risen** from ~0.7 W/m² in the mid-2000s to 1.8 W/m² by 2023, **i.e. roughly doubling over two decades**. **The models account for about half of the 2023 value.**¹²³ In contrast, a 2026 study found that all observed annual values, including 2023, fall within the range predicted by the models, and 13 out of 30 models also reproduce the average value for 2001–2025. However, only 10 models track the rate of increase, and models with an equilibrium sensitivity of 3–5 °C reproduce the measurements best.²⁹ The two results are not mutually exclusive, as one takes the magnitude of the record year 2023 as its benchmark, while the other takes the extremes of the entire range. From both, we conclude that the models underestimate the rate of increase.

VI/1. ábra. A földi energiamérleg többlete: megfigyelés kontra modellvárakozás.

W/m². Műholdas sugárzásmérés, óceáni hőtartalom-mérésekkel keresztellenőrizve.



Megjegyzés: A többlet két évtized alatt több mint kétszereződött, és 2023-ban a modell-becslés kétszeresén állt. A szerzők nem javasolnak mechanizmust – a közlemény megfigyelési állítást tesz, és kimondja, hogy az eltérés rendszeres, nem zaj. A magyarázatra több lehetséges ok van (aeroszoltisztulás, felhő-visszacsatolás, óceáni hőfelvétel), ezek közül a fejezet a következő pontban egyet bont ki.

Forrás: Mauritsen és mtsai (2025), AGU Advances; a modell-becslés az IPCC AR6 legjobb becslése.

The energy balance is usually reported in two different quantities, and mixing the two creates an apparent contradiction. The first caveat concerns the time window. The figure of 1.8 W/m² is a satellite-measured value for a single year, 2023, while the same balance, averaged **over twenty-year, overlapping time windows**, is lower and more consistent: 0.40 W/m² (1976–1995) → 1.04 W/m² (2006–2025) – this too has more than doubled, but without the noise. The two values do not contradict each other, as one is a single-year value and the other is a window average. The second limitation concerns the rate of change. The two measurement channels yield different results – between 2001 and 2025, the trend calculated from ocean warming is 0.30 ± 0.1 W/m² per decade, while that from satellite radiation measurements is 0.44 ± 0.13. Both are positive and accelerating, but their rates differ. Interpretations are also divided, yet the competing interpretations are compatible with one another: the rise in greenhouse gas concentrations, the weakening of aerosol cooling (VI.2), increased solar energy absorption resulting from reduced cloud and ice albedo, and – according to a 2026 analysis – specifically the decline in low-level cloud cover.¹²⁴

The same report also issues an important, standalone warning from a public administration perspective, namely that measurement capabilit-

ies are deteriorating. Satellites monitoring the energy balance are being taken out of service without replacement – meaning that we are losing the ability to observe the most telling variable at precisely the moment when it is behaving differently from ever before. This issue must also be represented by Hungarian environmental diplomacy in international consultations, in a manner commensurate with the country's standing.

Only a small proportion of the accumulated energy remains in the atmosphere. Since the 1970s, **around 90 per cent of the excess energy has been absorbed by the oceans, with 5 per cent going to the land, 3 per cent to the cryosphere and around 1 per cent to the atmosphere. This has two consequences, both of which affect planning.**

One consequence is that surface temperature is a misleading indicator in the short term. On a decadal timescale, oceanic heat redistribution can decouple surface temperature from the energy balance – a 'cooler' year does not mean that the system has slowed down. Ocean heat content is therefore a more robust indicator of the rate of change than air temperature.

Another consequence is that ocean warming **is accelerating**, at a roughly constant rate since 1960 of $0.15 \pm 0.05 \text{ W/m}^2$ per decade, while the combined acceleration for the land, cryosphere and atmosphere is 0.013 ± 0.003 – **an order of magnitude lower**. Furthermore, the warming is penetrating into deeper layers. The layer between 700 and 2,000 metres has been warming measurably since the 1990s, and more than half of the ocean's accumulated heat content since the end of the 19th century has been generated since the 1990s.¹²⁵

The vertical distribution, however, is changing, and this is significant in terms of the effects on the surface. Stratification in the upper ocean is intensifying. The density difference between the warming surface layer—which is becoming less salty due to meltwater from the poles—and the water mass beneath it is increasing, the mixing layer is becoming thinner, and the same excess energy is heating a smaller volume of water – this explains the measured increase in the seasonal fluctuation of sea surface temperature ($3.9 \pm 1.6 \%$ between 1983 and 2022) and the lengthening of marine heatwaves.¹²⁶ There is also evidence to the contrary in the literature, as over the last two decades it is precisely the heat uptake in the mode and intermediate water layers that has accelerated, while the deep ocean is warming measurably – the downward heat transfer has therefore not ceased.¹²⁷ The 2025 data set shows both trends. The heat content at depths of 0–2,000 metres set a new record, exceeding that of

2024 by approximately 23 ZJ, while the annual average sea-surface temperature was 0.12 °C lower than in 2024.¹²⁸ An assessment of the 2026 vintage was not yet available at the time of going to press, so the causes of this year's surface extremes remain an open question.

From a domestic perspective, the near-surface layer is more important than the total heat content, because the **surface** temperatures of the Mediterranean and the Atlantic Ocean determine the moisture reaching the Carpathian Basin and the marine background during heatwaves.

Why does this matter for a country far from the sea? Not because of a direct mechanism of influence, but because of the system's inertia. Energy absorbed by the ocean returns to the system on a timescale of decades or centuries. Put in practical terms, the climate in Hungary over the coming decade has largely already been determined – it does not depend on what happens with emissions between 2026 and 2035, but on what has already happened, and on the fact that emissions continue during this period (this distinction is explained in Section VI.6). Our argument is that emissions reductions between 2026 and 2035 will have little impact on the trajectory for the decade as a whole, but will have a greater impact on the trajectory after 2035. Adaptation therefore does not replace emission reductions, because the former manages the risk over the decade, while the latter determines the level of risk to which we will need to adapt after 2035. The two types of error are not symmetrical here either, because the impact of deferred emission reductions is irreversibly embedded in the trajectory for subsequent decades.

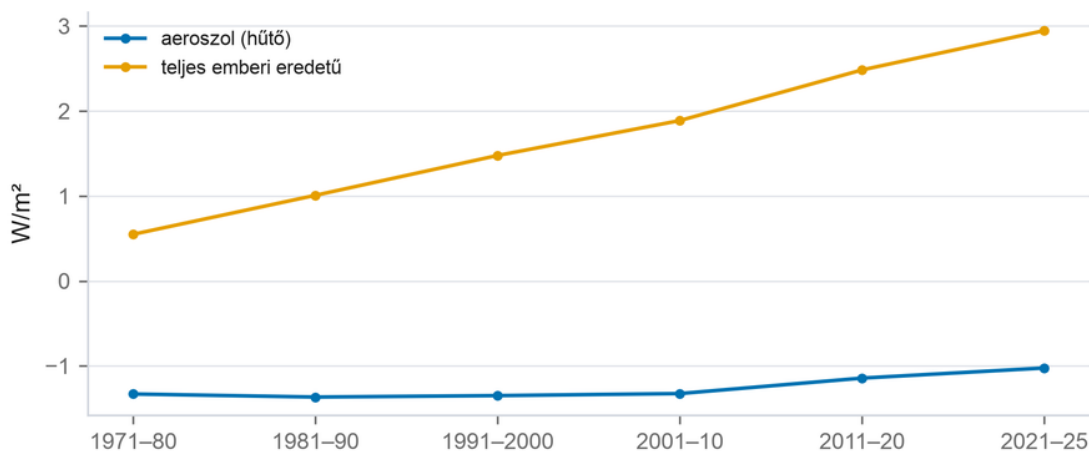
VI.2 Why the global and domestic projections are lower-bound estimates: aerosol clearance

Sulphur dioxide and soot entering the atmosphere have a cooling effect because they reflect sunlight and increase the albedo of clouds. For decades, this cooling effect **has masked** part of the greenhouse effect. The success of air quality protection is therefore a double-edged sword – as pollution decreases, the mask is removed.

The official forcing time series shows this broken down by decade.¹²⁹

VI/2. ábra. Az aeroszolhűtés és a teljes emberi eredetű kényszer, évtizedes átlagok.

Effektív sugárzási kényszer, W/m^2 , 1750-es referenciához mérve.



Megjegyzés: Az aeroszolmaszkolás a nyolcvanas években tetőzik, azután negyven évig alig mozdul – majd 2010 után gyorsan nyílik: a hűtő hatás 1,37-ről 1,03 W/m^2 -re gyengül. Ugyanebben az időszakban a teljes emberi eredetű kényszer 2,48-ról 2,95 W/m^2 -re nő. A két görbe együtt olvasandó: a melegedés gyorsulásához a kibocsátás növekedése ÉS a maszk lekerülése egyszerre járul hozzá.

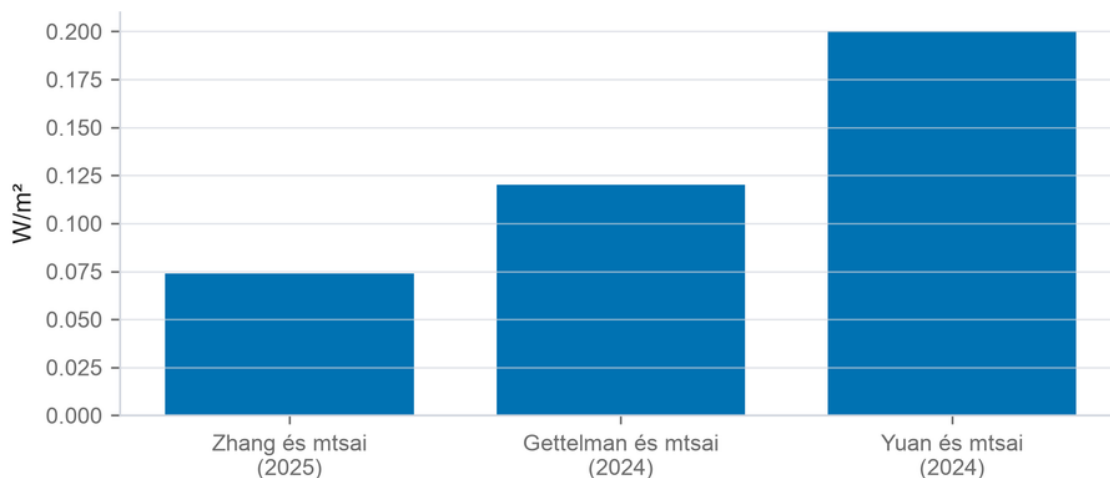
Forrás: IGCC 2025 effektív sugárzási kényszer idősor (Forster és mtsai), saját évtizedes átlagolással.

Two specific events underlie this phenomenon. One is the improvement in air quality in East Asia. Chinese sulphur dioxide emissions have fallen by roughly 20 Tg/year since 2010. Multi-model simulations attribute a significant proportion of the acceleration in warming since 2010 to this, and the spatial pattern of warming – concentrated in the mid-latitudes of the Northern Hemisphere, particularly over the Pacific Ocean – is also consistent with this.¹³⁰ The other is the **2020 limit on the sulphur content of marine fuel**, which has reduced the sulphur content of ship emissions by around 80 per cent.

The literature is divided on this latter point:

VI/3. ábra. A 2020-as hajózási kénszabályozás sugárzási hatása: három becslés.

W/m². Ugyanaz az esemény, három munkacsoport, csaknem háromszoros eltérés.



Megjegyzés: A közölt tartomány a teljes irodalomban nagyjából 0,02 és 0,2 W/m² között van – csaknem egy nagyságrend. A becslések térbeli hatóköre is eltér (globális óceáni átlag, illetve három hajóútvonal alacsonyfelhő-régiója), ezért közvetlenül nem is összemérhetők. A legmagasabb becslés szerzői a lépést nem szándékolt geomérnökség hirtelen leállításának nevezik; a legalacsonyabbéi azt hangsúlyozzák, hogy a jel a természetes felhőzet-változékonyság mellett alig kimutatható.

Forrás: Yuan és mtsai (2024); Gettelman és mtsai (2024); Zhang és mtsai (2025).

This does **not** mean that the rate of warming has permanently spiked. The forced effect of the regulatory measure is a **one-off shift in level**, not an acceleration of the greenhouse gas trend. If we treat it as a sustained acceleration, we are counting the same warming twice. Similarly, the record-high sea surface temperatures of 2023–2024 are a complex phenomenon in which an El Niño surge, the aerosol step and internal variability have superimposed themselves on the long-term warming trend. Furthermore, there is an unexplained residual. Taking all known factors into account, the planet was approximately 0.2 °C warmer in 2023 than the models predicted based on the known factors – El Niño, the reduction in sulphur emissions from shipping, solar activity and the 2022 undersea volcanic eruption. The scientific literature has not yet reached a consensus on the cause of this discrepancy, and we do not fill in this gap with speculation.¹³¹

Why is this important in the Hungarian context? Because aerosol clearance is also a **European phenomenon**, and it is one possible cause of the Hungarian model underestimation (H.2). If the aerosol cover over the continent cleared more rapidly than regional models predict, then the discrepancy between observed and projected warming stems partly from

this – this has not yet been proven, but is a **question that requires investigation**.

Equilibrium climate sensitivity (ECS) indicates how much the planet will warm in response to a doubling of atmospheric carbon dioxide. The IPCC's Sixth Assessment Report gives 3 °C as the best estimate, with a likely range of 2.5–4 °C. **The literature is not unanimous on this point, and this cannot be ignored.**

Observations are increasingly ruling out a low sensitivity, as models with a sensitivity below 2.5 °C fail to reproduce satellite radiation patterns. On the upper end, however, the uncertainty is high. Palaeoclimatological reconstructions suggest 4–5.3 °C, while Hansen et al. cite 4.8 ± 1.2 °C.¹³² This constitutes a substantive contradiction with the institutional best estimate, which cannot be resolved by averaging the figures. The debate, however, **remains open in both directions**. On the other hand, according to a 2026 estimate based on observational constraints, even the data updated with the record-breaking years of 2023–24 do not justify an upward revision of the range – the narrowed warming trajectory falls within the lower-middle part of the model range – and the ‘hot model’ correction also applies, whereby the model ensemble filtered against observed historical warming yields warming figures 8–16 per cent lower by the middle and end of the century than the raw model average.²⁵ The mid-point is therefore contested from both sides, and we do not endorse either position.

Underlying the debate is the unresolved issue that the acceleration of approximately 0.3 °C per decade observed since 2015 can be explained in two mutually exclusive ways. Either the waning of aerosol cooling is ‘unmasking’ the ever-present greenhouse effect – in which case the models’ sensitivity is correct, but their forcing estimate was incorrect. Or the baseline sensitivity is higher than assumed – in which case the models’ response is incorrect. The data currently available are consistent with both possibilities.

From a planning perspective, however, it is reassuring that the two interpretations point in the same direction. Whether the model is wrong in its forcing or in its response, the observed trajectory lies above the model median. The minimum rule of analysis – where verified at the indicator level – applies in both cases. The difference lies in the steepness of the trajectory after 2050, not in the direction for the coming decade.

VI.3 Is the global trajectory worse than the scenarios suggest?

Roughly half of the carbon dioxide emitted is absorbed by terrestrial vegetation and the ocean; it therefore does not remain in the atmosphere. This sink has so far functioned as a free service for climate policy – and since AR6, two mutually reinforcing findings have emerged indicating that **it is weaker than we thought and is deteriorating**. This paragraph is about carbon dioxide. Methane – the mitigation measure with the fastest impact over the next two decades due to its short atmospheric lifetime – will be discussed separately in the second half of this section.

The first finding is methodological. The terrestrial sink has so far been estimated from model runs that use **pre-industrial** land cover – that is, they assume more forest than there is today. This correction reduces the natural terrestrial sink by around 20 per cent.¹³³ The second finding concerns the process itself. According to the consolidated global carbon budget, **climate change is already reducing the efficiency of sinks**, and this has increased atmospheric carbon dioxide levels by 8.3 ± 1.4 ppm since 1960. Much of the tropical forest in South-East Asia and South America **has shifted from being a sink to a source** under the combined pressure of climate change and deforestation.¹³⁴

VI/4. ábra. A természetes szárazföldi szén-nyelő átértékelése.

PgC/év, 2015–2024. A korrekció a felszínborítási torzítást veszi ki.



Megjegyzés: A bizonytalanság rendre $\pm 0,94$, $\pm 0,77$ és $\pm 1,04$ PgC/év – a harmadik oszlopnál a bizonytalanság csaknem akkora, mint maga az érték. A korrigált nettó nyelő közel áll a légköri mérésekből független úton kapott értékhez, ami az átértékelést megerősíti. Tervezési következmény: ugyanaz a kibocsátás több légköri szén-dioxidot eredményez, mint amennyivel a korábbi mérések számoltak.

Forrás: O'Sullivan és mtsai (2026), npj Climate and Atmospheric Science; Friedlingstein és mtsai (2026), Nature.

A significant proportion of the reassessment of the sink stems from improvements in estimation methods, not from any newly observed decline, as the terrestrial sink did not become smaller from one year to the

next; it had simply been wrongly estimated until now. The claim regarding the decline is independent of this, and is supported by the figure of 8.3 ppm. To cite the two together would be inaccurate.

Methane is the second-largest anthropogenic greenhouse gas, and, due to its short atmospheric lifetime, it is the only one where the effects of intervention would be visible even over a period of decades.

indicator	value	comment
atmospheric concentration, 2024	~1922 ppb	approximately two and a half times the pre-industrial level
Annual increase, 2020–2022	13–18 ppb/year	record years in the measurement series
annual increase, 2023–2024	7–11 ppb/year	significant slowdown compared with the record years
temperature sensitivity of peatland emissions	+24 ± 10 Tg/year per °C	estimate refined by observation
peatland emissions in the 2090s	+50–60 % compared with the 2010s	with ~5 °C of land-based warming

The concentration level is robust, **but the exact value of the annual increase depends on the data source**, as different official analyses give increases ranging from 8.7 to 11.1 ppb **for the same year, 2023**. The trend towards a slowdown is evident in all of them, but the extent of this cannot be directly compared.¹³⁵

The substantive new finding since AR6 concerns feedback, not concentration. According to an estimate based on a model ensemble comprising seven models and 163 station-years of direct flux measurements, methane emissions from peatlands increase linearly by 24 ± 10 Tg per year for every degree of land-based warming, and by the end of the century, they will have risen by 50–60 per cent compared with the 2010s.¹³⁶ From a policy perspective, the short-term implications are the most significant. The increase expected by the 2030s will, with a 90 per cent probability, reach 10 Tg per year – this represents 8–10 per cent of the reduction targeted by the global methane commitment; however, with a 10 per cent probability, it will amount to 33–39 per cent. In other words, rather than being a net reduction, part of the commitment will be used to offset this feedback. From a mitigation perspective, this implies that methane reduction is not a secondary consideration. The impact of carbon dioxide reductions accumulates primarily on the longer-term trajectory after 2035, whereas the impact of methane reductions is the soonest to show in global temperature, already between 2035 and 2050, and the domestic

commitment must also make up for the proportion taken away by feedback.

The validity of the estimate is limited by the fact that the majority of the measurements providing the observational constraint come from mid- and high-latitude regions, while approximately two-thirds of the estimated increase occurs in the tropics. The lack of observations in the tropics is the main weakness of the estimate, as the authors themselves point out.

VI.4 The amplitude of extremes

The behaviour of extremes is the least well-known aspect of the global picture, yet it is the most important from a planning perspective. These events are becoming more frequent, and the magnitude of their outliers is also increasing.

The frequency aspect is easier to understand. This year's update introduced the number of days with marine heatwaves as a new indicator; this figure more than tripled between 1991 and 2025, reaching 65 days in 2025. While this is to be expected given rising average temperatures, the extent of the increase is not.

The amplitude aspect is the more important one. According to the literature on record-breaking events, in a warming climate more records are broken, and these records are broken with greater leaps – alongside a shift in the distribution, the likelihood of events occurring far from the long-term average also increases.¹³⁷ This is accompanied by two mutually reinforcing findings: **models consistently underestimate** the observed temperature scaling of extreme precipitation, and even under moderate global warming, spatially coherent extreme outcomes may occur that exceed the multi-model means for 3–4 °C of warming.

This line of reasoning is conceptually related to the structural change in domestic precipitation described in section II.4 and to the Hungarian summer of 2026 [synthesis, not a source], as each is underpinned by the assertion that planning must be scaled not to the shifting mean, but to the widening range of extremes. Quantitative extrapolation, however, is not permitted, as neither the global scaling value nor the probability of record-breaking events can be directly applied to Hungarian design values.

VI.5 Open extreme value ranges

Finally, we leave three questions open, as these have not been clarified since AR6: the future of the Atlantic Meridional Overturning Circulation (AMOC), the strength of cloud feedback, and the unexplained residual of approximately 0.2 °C for the year 2023. The scientific literature is divided on the extent and timing of the AMOC's weakening. Each of these represents an uncertainty whose **distribution is open in both directions** – and within the risk framework, the upper extreme range is the more costly.

VI.6 Transfer – what it changes in the domestic interpretation, and what it does not

The global picture contributes three elements to the domestic risk assessment and omits three. It provides a **baseline class**: the broader set of cases against which the observed domestic trends can be measured. It provides a **direction for managing uncertainty**: where global observations lie at the edge of the model's expectations, the domestic model range should not be interpreted as a mean value, but rather its bottom is a lower bound, while the planning minimum is the observed value (H.2). It provides an **extreme-value interpretation**: the sizing relates to the edge of the distribution, not its mean. However, it does not provide a domestic loss estimate, nor a basis for the interplay between domestic impact chains, nor an order of intervention – these are covered in the domestic chapters (I–V and VII–IX). Where the global picture does not provide a domestic baseline value, we indicate this and do not substitute it with an estimate.

- **The minimum rule used in the analysis has a global counterpart.** Most models underestimate the increase in the energy balance surplus (VI.1), while the rate of warming over the past decade and a half lies at the top end of the range for CMIP5 models and in the upper part of the range for CMIP6 models.²²¹ According to a 2026 study, the average of the CMIP6 models underestimates the 2011–2025 rate by around 28 per cent.²²³ A third detail, relevant from the perspective of continental countries, is derived from the annually updated set of global indicators¹²²: the observed land–ocean warming ratio, which is 1.75 (land +1.81 [1.63–2.07] °C, ocean +1.03 [0.83–1.14] °C, 2016–2025, relative to the 1850–1900 baseline). This does not prove that domestic models are underestimating the warming – the quantities and scales are different, and the ratio is a **global mean** that does not support a claim specific to the Carpathian Basin – but **it points in the same direction**, and this parallel is the only argument that does not stem from domestic data.

- **Aerosol clearing is one possible mechanism.** If European and domestic regional models underestimate the rate at which the aerosol mask is being lifted, this partly explains the discrepancy between the observation and the projection (H.2). This needs to be investigated; it has not been proven.
- **The issue of sinks is a boundary condition, not a Hungarian variable.** Hungary's emissions policy does not influence the state of tropical forests; however, a weakening sink means that **the same level of global emissions results in more atmospheric carbon dioxide**, so the global trajectory underlying domestic planning is worse than that assumed by the referenced scenarios.
- **Methane feedback is a factor on the mitigation side, not the adaptation side.** It is included in this analysis because, in the domestic climate policy debate, methane commitments are regularly presented as a net gain – which, according to the figures above, they are not.

Four conclusions follow from the above. (1) The accumulation of surplus energy is accelerating, and this acceleration is a measured value, not a modelled one (VI.1). (2) **The climate trajectory for the coming decade is largely determined**; therefore, it makes sense to discuss adaptation planning with a decade-long horizon, and in the following paragraph we explain what determines this trajectory and what does not. (3) The sensitivity debate broadens the trajectory beyond 2050, not that of the next ten years. (4) Due to the weakening of sinks and methane feedback, the global trajectory underlying domestic planning is worse than that assumed by the referenced scenarios (VI.3).

A clarification is needed here, as this issue recurs in the domestic expert debate. 'Committed warming' does not mean that the energy stored in the system would cause further warming on a decade-scale. According to the literature, the rise in global temperature will largely come to a halt once carbon dioxide emissions cease. The best estimate of the temperature change after net-zero carbon dioxide emissions (ZEC), according to AR6, is 0 ± 0.3 °C, with low confidence in the direction of the signal.¹³⁸ The trajectory for the coming decade is therefore not determined by physical inertia, but by the fact that emissions will not cease during this period, as net-zero emissions within ten years would only be achievable through a drastic transformation or collapse of the economic system. Apart from these scenarios, the item is of **theoretical significance** in the 2026–2035 planning period. **The underlying cause persists, so the measured rate of warming remains the starting point for planning.**

Two comments are required regarding this picture:

(1) The ZEC relates to carbon dioxide, whereas the cessation of aerosol emissions has the opposite effect, leading to a short-term warming step (VI.2).

(2) A ZEC close to zero is the result of the cancellation of two major components. **Approximately +0.2 °C of as-yet-unrealised ocean warming** is offset by approximately –0.2 °C resulting from carbon dioxide removal by terrestrial and ocean sinks, while the standard deviation of the heat term across models is more than twice that of the carbon cycle term.¹³⁹

If the finding in Section VI.3 holds true – that sinks are weaker than the values recorded in the inventories and are deteriorating – this works against the offsetting term. This is our own interpretation arising from the combination of the above source and the finding in Section VI.3. In the risk framework, a zero ZEC represents the equilibrium of two uncertain, opposing processes, not a state of rest.

However, four conclusions do not follow from the picture outlined above.

(1) It does not mean that any of the domestic figures can be derived from the global data – warming in the Carpathian Basin is above the global average (II.1), but the ratio is not constant, and we do not report such a multiplier. (2) It does not mean that the ‘minimum rule’ of the analysis has been validated globally, because the rule must be validated for each variable, and neither the global energy balance nor the land/ocean ratio validates any specific domestic indicator. (3) It does not mean that we endorse the higher sensitivity estimates, as we are presenting the debate, not settling it. (4) Finally, it does not mean that global uncertainty would suspend domestic planning – quite the contrary: the measured accumulation of excess energy and the measured rate of warming make the coming decade more predictable, not more uncertain.

This chapter provides context, but no domestic attribution, as no single domestic event, year or trend can be derived from it. The global picture serves as **context and boundary conditions**; the evidence for domestic claims remains the measurements in Chapters I–III.

The figures in this chapter are updated annually, and these updates can be significant – this edition presents data for the year 2025, as of June 2026. The domestic figures in the analysis are based on fifty-five-year time series, whereas these are not. The two kinds of figure have different lifetimes, **and the values in the global picture should not be regarded as being as stable as the domestic trends.**

indicator	interpretation of the AR6 cycle	current reading	status
energy balance surplus	~0.9 W/m ²	1.8 W/m ² (2023)	observation; annual values are within the model range, while most models underestimate the rate of increase (VI.1)
rate of anthropogenic warming	–	0.27 °C per decade (2016–2025)	annually updated indicator
aerosol cooling	~–1.3 W/m ² , gradually weakening	–1.03 W/m ² (2021–25)	accelerating opening after 2010
natural terrestrial sink	3.0 PgC/year	2.42 PgC/year	methodological correction
climatic degradation of sinks	qualitative	+8.3 ± 1.4 ppm since 1960	new quantitative estimate
wetland methane feedback	wide, unconstrained range	+24 ± 10 Tg/year per °C	narrowed by observations
2023–24 sea-surface record	–	composite: El Niño + aerosol step + residual	to be separated by cause, not cited as a single entity

VII

Outlook to 2050

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KEY FINDINGS

Planning basis	Planning should assume global warming of at least 2 °C around 2050. The stress test level is 2.5 °C, and the extreme scenario level is 3 °C.
Favourable scenario	On one of the most favourable assessed pathways, if all commitments and net-zero targets are met, warming will peak at around 1.8 °C. Even the most stringent pathways, starting in 2025, do not achieve the 1.5 °C limit: these have a 50 per cent chance of peaking at 1.6–1.8 °C, with 1.6 °C being the lower end of this range. None of these levels can be counted as a saving.
Post-net-zero temperature	The temperature following the cessation of emissions depends on the behaviour of the oceans and carbon sinks. Stabilisation is the best estimate, not a guarantee. The <i>Danube</i> . The volume of the Alpine glaciers will fall by about half by 2050, and the snow cover will also diminish. Winter water flow will increase, while summer reserves will be lower; studies differ regarding the summer average.
Tipping points	These will affect Hungary via atmospheric circulation, the flow of the Danube, the rise in the global warming trajectory, and, in the longer term, through sea level and the EU economy. The weakening of the Atlantic deep-water current does not cancel out domestic warming.

Beyond a ten-year horizon, domestic measurements no longer provide a direct reference point, and domestic climate projections, according to [H. 2](#), underestimate four indicators. This chapter therefore raises questions regarding risk management: what should we plan for by 2050, what can be avoided in a best-case scenario, and what should we monitor? We adopt this approach from the field of actuarial science.¹⁴⁰ In addition to the most likely outcome, the actuary also asks what is possible and works backwards from scenarios leading to failure, a process known as a reverse stress test ([VIII.5](#)). Where two well-founded estimates differ, a stress test is also built around the less favourable one.

This chapter uses three terms to indicate the likelihood of an event occurring. We describe as ‘likely’ that which, according to the majority of sources, is more likely to occur than not. We describe as ‘possible’ that which well-founded sources consider realistic, but which is not the central outcome. Finally, we describe as ‘unlikely’ that which requires the concurrence of several conditions, but cannot be ruled out. This classification is our own assessment based on the sources cited in this chapter. We do not provide calculated probabilities because, for the 2050 horizon, the role of measurement is largely taken over by modelling and expert judgement, and the combined probability of individual risks cannot be reliably estimated ([VIII.3](#)).

VII.1 Global temperature around 2050: three planning levels

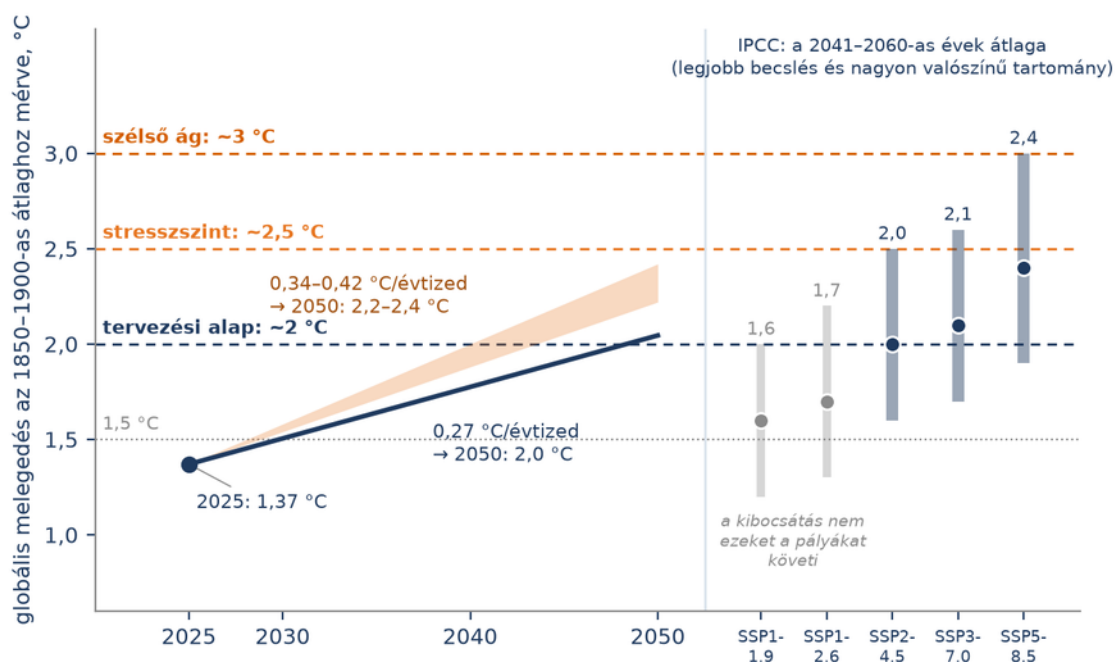
Anthropogenic warming stood at 1.37 °C in 2025, having increased at a rate of 0.27 °C per decade over the past decade ([VI.1](#)). A 2026 study indicates a faster rate after accounting for the effects of natural variations (El Niño, volcanic eruptions and solar activity). Across five global datasets, it found warming of 0.34–0.42 °C per decade since 2013–2014, and demonstrated this acceleration with a confidence level of over 98 per cent.¹⁴¹ Another study from 2026, which is yet to be finalised, found – without filtering out natural variability – a rate of 0.40 °C per decade across five data sets between 2011 and 2025, twice the rate observed between 1971 and 2025. Projecting this trend linearly, warming will reach the 1.5 °C threshold—as defined by the IPCC’s twenty-year timeframe—around 2028 (2026–2031), and the 2 °C threshold around 2040. In this study, the acceleration cannot be statistically demonstrated without the record-breaking year of 2024, and according to the authors, the projection to the 2 °C threshold is less reliable than that to the 1.5 °C threshold.²²³ If the rate of 0.27 °C continues, warming will reach 2.0 °C by 2050. If the accelerated rate persists, it will be 2.2–2.4 °C; with a rate of 0.40 °C, it will be approx-

imately 2.4 °C (our own calculation; Figure VII/1). Each scenario remains below the 2.5 °C stress threshold.

Together, the two rates define the design range. The acceleration is evident in five measured data sets (see the paragraph above and note 223), but statistically it currently rests on the record year of 2024. The cost of error, however, is asymmetric: if the planning disregards the actual acceleration, the damage is greater and more difficult to rectify than if it were to prepare for an acceleration that proves to be temporary. The 2 °C threshold is therefore the lower limit for planning: it follows from the continuation of the longer-term trend and corresponds to the IPCC's estimate for the medium pathway. The 2.5 °C stress level covers the scenario in which the already observed accelerated rate persists until 2050, and in our judgement this is at least as likely as the baseline scenario. Whether it persists depends on how quickly the residual aerosol cooling ceases (VI.2) and to what extent sinks weaken (VI.3). This cannot be determined at present; therefore, the higher rate forms the basis of the stress test. The stress scenario does not account for the one-off level change described in VI.2 a second time. It applies to the case where residual aerosol cooling continues to decline steadily until 2050, sinks weaken, or climate sensitivity is higher than assumed.

FIGURE VII/1

Global warming around 2050: two projections based on the measured rate and the IPCC ranges.



°C relative to the 1850–1900 average. Left-hand side: extrapolation from the 2025 value. Right-hand side: the average for the 2041–2060 period across five emissions scenarios.

SOURCE Forster et al. (2026); Foster and Rahmstorf (2026); IPCC (2021), Table SPM.1; extrapolation based on own calculations.

NOTE The extrapolation is a simple arithmetic operation, not a forecast. It relates to the year 2050 and can therefore only be compared approximately with the twenty-year average. The two low-emission scenarios assume an immediate, steep reduction in emissions, which has not materialised (VII.2), and are therefore shown in grey.

The IPCC's Sixth Assessment Report gives a figure of 2.0 °C for the average temperature in the period 2041–2060 on the medium emissions pathway, with a very likely range of 1.6–2.5 °C. The estimate is 2.1 °C (1.7–2.6) on the high pathway and 2.4 °C (1.9–3.0) on the very high pathway. The 1.6–1.7 °C values for the two low pathways assume an immediate, steep reduction in emissions, which has not materialised (VII.2).

Three institutional assessments point in the same direction. According to the World Meteorological Organisation's (WMO) 2026 forecast, there is a 75 per cent chance that the average for the 2026–2030 period will exceed 1.5 °C. The UK Climate Change Committee's 2026 risk assessment treats a 2 °C rise by 2050 as a minimum planning assumption and does not rule out a 4 °C rise by 2100. According to a report published by the UK Actuarial Society, warming in excess of 2 °C is likely before 2050 if the current trajectory remains unchanged. Warming in excess of 3 °C by 2050 is possible if high climate sensitivity and sustained acceleration occur simultaneously, although the probability of this is low.¹⁴²

planning level	global warming around 2050	evidence	role in planning
basis	~2 °C	continuation of the measured rate; the IPCC's medium-range scenario; the UK's minimum planning assumption	the baseline for all instruments and standards in operation up to 2050
stress	~2.5 °C	continuation of the accelerated rate (2.2–2.4 °C) with a margin; the upper limit of the IPCC's medium-range scenario	mandatory sensitivity analysis on the minimum-rule indicators and on long-life facilities
extreme scenario	~3 °C	the upper limit of the IPCC's very high scenario; high sensitivity combined with sustained acceleration	storyline

What do the three levels mean in the Carpathian Basin?

The three levels are global values from which national values cannot be derived by simple multiplication (VI.6). The national estimate is based on how much global climate models project the region to warm over the twenty-year period during which the global average reaches the given level. We calculated this from the public regional database of the IPCC's Sixth Assessment Report, using runs from 35 global models (CMIP6) and the IPCC's warming level method.²²⁹ Hungary lies on the southern edge of the Western and Central European region, on the border with the Mediterranean region; therefore, the table below presents land-based values for both regions, relative to the 1991–2020 normal. Global levels, however, measure warming relative to the pre-industrial average for 1850–1900, and the global average for 1991–2020 was already approximately 0.9 °C above this.²³⁰ To ensure that the national and global figures are based on the same reference, the first column of the table also states, in brackets, the extent of global warming relative to the 1991–2020 global average: approximately 1.1 at the 2 °C level, 1.6 at 2.5 °C, and 2.1 °C at 3 °C. Measured on the same basis, the region is therefore warming approximately 1.4–1.5 times as fast as the global average. Compared with pre-industrial levels, the Western and Central European region is approximately 2.7 °C warmer at the 2 °C global level, 3.3 °C warmer at 2.5 °C, and 4.0 °C warmer at 3 °C. The range in brackets represents the middle two-thirds of the model runs.

In the models, this amplification is smaller than the value measured in recent decades, as described below. One reason for this difference is the reduction in sulphur pollution: sulphur dioxide emissions in Europe have

fallen sharply since 1990; in Hungary, they fell from 832,000 tonnes to 30,000 tonnes between 1990 and 2010, to barely 4 per cent of the previous figure.²⁴² The improving air quality allows more solar radiation to reach the surface, and model studies attribute around a quarter of the warming observed in Europe since 1980 to this, and an even larger proportion of the summer warming.²⁴³ As this decline has largely already taken place, a 2025 study suggests that Europe's excess summer warming may be significantly lower in the coming decades,²⁴⁴ which is consistent with the models' smaller future amplification. Nevertheless, we treat this as a lower-bound estimate, as these same models also underestimated past warming in Europe, primarily the component arising from changes in atmospheric circulation, the cause and persistence of which are not unanimously agreed upon in the literature.²⁴⁵ Our own hypothesis is that the remaining reductions in sulphur emissions in Poland and the Western Balkans may further increase warming in the region.

global level relative to the pre-industrial average (with the 1991–2020 global average in brackets)	annual mean temperature, °C (Western and Central Europe / Mediterranean)	summer mean temperature, °C (Western and Central Europe / Mediterranean)	summer and winter precipitation, % (Western and Central Europe / Mediterranean)
2 °C (+1.1 °C)	+1.7 (1.3–2.1) / +1.5 (1.2–1.9)	+1.9 (1.3–2.4) / +2.0 (1.4–2.4)	summer –6 / –12; winter +5 / –3
2.5 °C (+1.6 °C)	+2.2 (1.8–2.7) / +2.1 (1.7–2.5)	+2.5 (1.9–3.2) / +2.7 (2.1–3.1)	summer –8 / –17; winter +8 / –4
3 °C (+2.1 °C)	+2.9 (2.4–3.3) / +2.7 (2.3–3.0)	+3.3 (2.6–3.8) / +3.4 (2.8–3.8)	summer –10 / –21; winter +10 / –5

The models have so far underestimated the observed warming in Hungary. The annual mean temperature in Hungary rose by 1.51 °C between the 1971–1990 and 2006–2025 periods, while the global average rose by 0.70 °C; in other words, the rate of warming in Hungary was 2.2 times faster.²³⁰ For the same period, the models indicate a 1.9-fold amplification (1.6–2.3) in the Western and Central European region. As there is no specific model value for Hungary in the regional database, the measured domestic amplification is compared with the regional model average. This is not the global-domestic multiplier rejected in Section VI.6, but a proportional correction for the discrepancy between the model and the measured data. When corrected in proportion to this difference ($2.17/1.92 = 1.13$ -fold), the domestic annual warming, measured against the 1991–2020 normal, is approximately 1.9 °C at a global level of 2 °C, 2.5 °C at 2.5 °C, and 3.3 °C at 3 °C. This is our own estimate; however, according to the 'planning minimum' rule (H.2), this figure takes precedence

over the model values in the table when determining the annual mean temperature.

These figures are best understood when compared with measured summers. The national average temperature in the summer of 2026 was 2.59 °C higher than the 1991–2020 normal, and was the second warmest since 1901 (II.2). According to the models, at a global warming level of 2 °C, summers are on average 1.9–2.0 °C warmer than normal; at 2.5 °C, 2.5–2.7 °C warmer; and at 3 °C, 3.3–3.4 °C warmer. In a 2.5 °C world, therefore, the summer of 2026 is considered an average summer according to the median of the models; when adjusted in proportion to the measured amplification, it is rather below average. In a 3 °C world, the average summer is warmer than the summer of 2026 even without any adjustment. The average number of extremely hot days for 2021–2025, at 8.5 days per year (II.1), is already the lower limit even at the 2 °C level, because the summers of 2020–2025 were approximately 1.3 °C warmer than normal, while the average summer at the 2 °C level is even warmer than this. These figures are the median values from the models; the actual values are likely to be higher due to the underestimation mentioned above. The comparison is based on our own interpretation.

Heat indices are not reported by the regional database of global models; we calculated these from the 28 regional runs of the Hungarian FORESEE-HUN dataset. For each run, we considered the twenty-year period during which the global model driving the run reaches the given level.²³¹ The table below shows the national average; the observed values are taken from the HungaroMet homogenised daily grid, which also supplies the measured branch of the same database.

	hot days (≥ 30 °C), days/ year	extremely hot days (≥ 35 °C), days/year	tropical nights (≥ 20 °C), nights/year
measured, 1991–2020	28	2.8	1.9
measured, 2006–2025	36	4.9	3.6
2 °C (+1.1 °C)	39 (38–46)	7.7 (6.1–9.5)	7.6 (5.9–10.3)
2.5 °C (+1.6 °C)	44 (39–48)	8.9 (6.2–10.7)	10.9 (7.7–13.4)
3 °C (+2.1 °C)	47 (43–52)	9.9 (8.6–12.7)	14.8 (12.5–18.4)

Regional projections also underestimate the increase in heat here. They predict 7.7 extremely hot days per year at the 2 °C level, which is fewer than the average already recorded on the official grid between 2021 and 2025 (8.5 days, II.1), even though that occurred at a level of global warming of around 1.3 °C. The minimum rule in H.2 does not apply to ex-

tremely hot days for the coming decade because the model range overlaps with the measured data in that period. As regards the 2050 levels, our own conclusion is that it is unjustified to plan below the measured 2021–2025 average, while the table's values for 2.5 and 3 °C should be regarded as lower estimates. Comparing the five-year measured average with the twenty-year model window biases the comparison against the model (H.2); therefore, this is an indication, not proof. For tropical nights, the model runs already show values at the 2 °C level that are approximately four times the 1991–2020 measured value and twice that of the 2006–2025 period (7.6 per year); though this still barely exceeds the measured average for 2021–2025 (6.6 per year, II.1).

The same is shown by the EURO-CORDEX database of the Copernicus Climate Atlas, which contains 71 regional runs from a wider range of models than FORESEE-HUN.²⁴⁶ At a global warming level of 2 °C, the annual mean temperature in these scenarios rises by only 1.0 °C (0.8–1.4) compared with the 1991–2020 normal; at 2.5 °C, it rises by 1.6 °C; and at 3 °C, by 2.1 °C. Between 2021 and 2025, however, with global warming of around 1.3 °C, the country was already 1.2 °C warmer than normal. The number of extremely hot days, when the change in runs is added to the measured 1991–2020 value, is 5.8 (3.5–11.3) per year at 2 °C, 7.8 at 2.5 °C, 10.8 at 3 °C, and for tropical nights 8.8, 12.9 and 18.7 respectively. The figure for extremely hot days at 2 °C also falls short of the 8.5 days measured for 2021–2025. According to a 2024 study, many regional models assume constant aerosol loading; consequently, they do not reflect the warming in Europe resulting from the reduction in sulphur pollution.²⁴³ We therefore treat these values as lower estimates and present the FORESEE-HUN table for the heat indices.

Summer precipitation is projected to decrease in both regions in the majority of models. Winter precipitation, on the other hand, is projected to increase in the Western and Central European region, while decreasing in the Mediterranean region. Hungary lies on the border between the two regions; consequently, the sign of the change in winter precipitation here is uncertain, while a decrease in summer precipitation is more likely. Warming and the decline in summer precipitation together reinforce the depletion of water reserves described in Chapter III, while any increase in winter precipitation only offsets this if it actually improves winter recharge (III.1). The table deliberately does not specify years. Which level occurs when is determined by the global rate described above, not by the regional model.

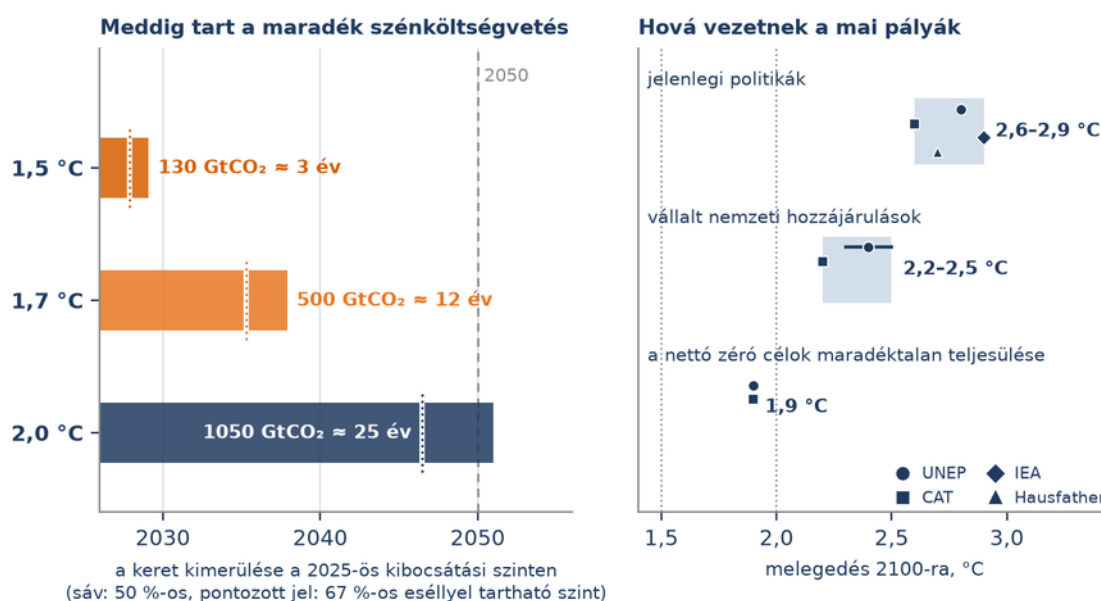
VII.2 The stabilisation level: 1.8 °C is the favourable case, 1.5–1.6 °C is the favourable extreme case

Warming will stabilise at the level determined by the cumulative emissions up to the point of achieving net-zero carbon dioxide emissions. The amount of carbon dioxide whose emission would still allow a given temperature level to be maintained is referred to as the residual carbon budget. The 1.5 °C budget stood at 130 billion tonnes at the start of 2026, with a 50 per cent probability. At the 2025 emission level of around 42 billion tonnes per year, this will be exhausted within three years. The 1.7 °C budget is sufficient for 12 years, and the 2 °C budget for 25 years (Figure VII/2; the number of years is based on our own calculations).¹⁴³

The stabilisation level rises with delay. According to the United Nations Environment Programme's (UNEP) 2026 report on 'overshoot' – that is, the temporary exceeding of the 1.5 °C threshold – every additional five years of emissions at current levels raises the peak level by approximately 0.1 °C. The more than 400 billion tonnes of carbon dioxide emitted since 2015 have already raised the lowest achievable level by around 0.2 °C.¹⁴³

FIGURE VII/2

The remaining carbon budget will be exhausted within three years under the 1.5 °C scenario; current policies and commitments will lead to temperatures exceeding 2 °C by 2100.



Left-hand side: the year the budget is exhausted, assuming emissions remain unchanged. Right-hand side: temperature projections for 2100 from four assessments, based on three scenarios.

SOURCE Forster et al. (2026), Table 8; UNEP (2025); Climate Action Tracker (2025); IEA (2025); Hausfather (2025). The number of years is based on our own calculations.

NOTE The categories used in the four assessments are not identical; therefore, we do not report an average, only the range. The UNEP figures represent levels with a 66 per cent probability of being met; the others are mid-range values. The IEA figure represents the 'current policies' scenario; the WEO 2025 does not provide an NDC-based scenario, while its net-zero scenario is a prescriptive trajectory. Hausfather (2025) provides figures based solely on current policies.

Stabilisation at 1.5–1.6 °C therefore assumes a trajectory in which global emissions fall to a fraction of their current levels within a few years. The IPCC's lowest-emission scenario, which projects 1.6 °C for 2041–2060, assumes deep reductions starting in 2015–2020, net-zero around 2050 and subsequent net-negative emissions. According to the UNEP report, such early-start trajectories are no longer feasible. Even the most stringent trajectories, which take actual emissions up to 2025 into account, peak at 1.6–1.8 °C, with a 50 per cent probability. By contrast, emissions in 2025 were still around 42 billion tonnes per year. Actual commitments fall far short of this level of reduction. Based on the pledges submitted by November 2025, global emissions could be around 12 per cent below 2019 levels by 2035. A 35 per cent reduction would be required to stay within the 2 °C limit, and a 55 per cent reduction for the 1.5 °C limit.¹⁴³

Current trajectories are therefore leading to higher levels. Under current policies, global temperatures are projected to reach 2.6–2.9 °C by 2100; the Nationally Determined Contributions (NDCs) would result in 2.2–2.5

°C; and full achievement of net-zero targets, according to both UNEP and the Climate Action Tracker, would result in warming of around 1.9 °C (Figure VII/2). The UNEP 2026 report presents a similar picture based on median values. Under current policies, warming will reach around 2.6 °C (1.9–3.6 °C) by 2100. In one of the most favourable scenarios, with all commitments and net-zero targets met, it will peak at around 1.8 °C (1.7–2.2 °C), and even then there is only about a 20 per cent chance of keeping it below 1.5 °C.¹⁴³ According to the Hamburg assessment, which specifically examines societal feasibility, none of the ten societal drivers examined supports deep emissions reductions through to 2050. The assessment therefore does not consider it plausible to stay within the 1.5 °C limit. It considers it achievable to keep global warming well below 2 °C only if the gaps in commitments, implementation and knowledge are closed.¹⁴⁴

Favourable trajectories are also subject to a further risk. The intensification of climate impacts may weaken the capacity for both emission reductions and adaptation, pushing the system towards less favourable trajectories. The literature refers to this as the ‘derailment risk’; its mechanism is described in Section VIII.3.

Within the risk framework, two favourable levels must therefore be distinguished. A peak of around 1.8 °C is the favourable scenario: it is possible, but assumes the full fulfilment of all commitments, which is not implied by current policies. A peak of 1.5–1.6 °C is the favourable extreme case: it is unlikely because it requires an immediate, unprecedented rate of emissions reduction. Such a rate of reduction is inconceivable without a drastic transformation or collapse of the economic system. Section VI.6 reaches the same conclusion regarding net-zero within ten years. We arrive at this conclusion from the figures in the carbon budget and the commitments, and we present it because the level at which warming stabilises determines what adaptation must be designed for. The median value of the favourable scenario, based on the peak level, remains below the 2 °C planning baseline around 2050. However, planning is not sized to this, as this scenario depends on the full implementation of the commitments, whereas the planning baseline depends on the measured rate. The planning baseline is 2 °C around 2050, which will continue to rise after 2050 until emissions cease.

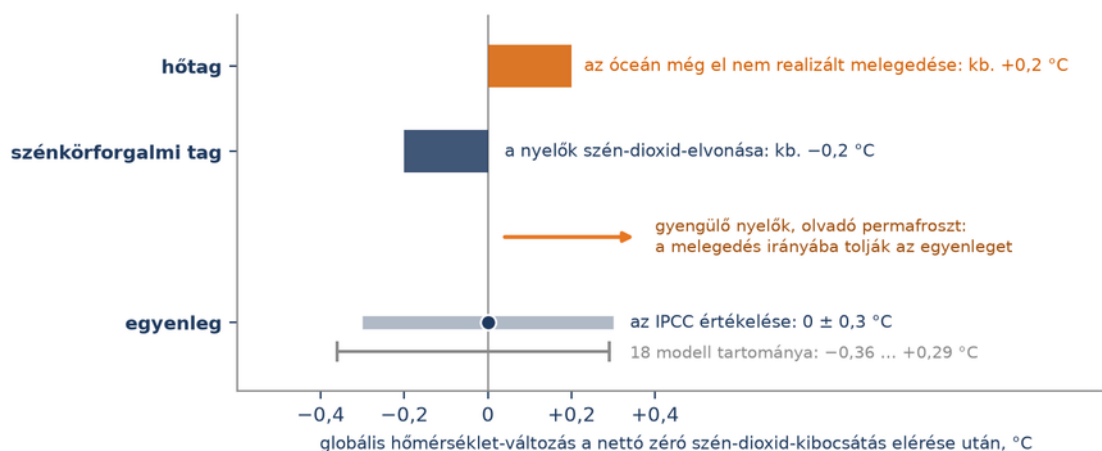
VII.3 Temperature after net-zero: the role of the ocean and carbon sinks

According to Section VI.6, the best estimate of temperature change following the cessation of carbon dioxide emissions is zero, with a range of ± 0.3 °C, and the direction of the signal is uncertain. This estimate is often interpreted to mean that warming will stop immediately upon reaching net zero. The risk-based interpretation is more cautious for four reasons.

- 1 Zero is the difference between two large, opposing effects (Figure VII/3). According to a ten-model study currently under peer review, the ocean's as-yet-unrealised warming over fifty years amounts to approximately $+0.2$ °C, while carbon dioxide removal by sinks amounts to approximately -0.2 °C – this is an indicative order of magnitude. The balance therefore depends on the future of the sinks.
- 2 Sinks weaken as emissions fall. In an idealised experiment carried out in a 2026 study using a single Earth system model, the Southern Ocean – which currently accounts for 40–50 per cent of oceanic carbon dioxide uptake – turns from a sink into a source around the time emissions cease. In the same experiment, the ocean as a whole remains a sink, but a much weaker one than at present. Carbon losses from permafrost and peatlands are under-represented in most models, and are likely to tip the balance towards warming.¹⁴⁵
- 3 The halt applies to carbon dioxide. Emissions of cooling aerosols will decrease alongside the phasing out of fossil fuel combustion, and this will cause warming in the short term (VI.2). Reducing methane is a separate requirement (VI.3).
- 4 Both the level and the timing of the halt matter. The higher the temperature at which the world reaches net zero, the more tipping point thresholds it may cross in the meantime (VII.6), and the effects of these will not be reversed once emissions cease. The melting of ice sheets and the rise in sea level will continue for centuries even after surface temperatures have stabilised.

FIGURE VII/3

The temperature change after reaching net zero is the difference between two major, opposing effects.



°C. A balance around zero is not a state of equilibrium: the weakening of sinks pushes the system towards warming.

SOURCE IPCC AR6; MacDougall et al. (2020); Sanderson et al. (2026, preprint); Palazzo Corner et al. (2023).

NOTE The values for the two terms are taken from a preprint based on ten models currently under peer review; they are therefore indicative of the order of magnitude. The range from the eighteen models (MacDougall et al. 2020) refers to the state fifty years after emissions have ceased.

According to the literature review, the possibility of further warming after net-zero is a real one – there is a non-negligible chance that this increase will exceed 15 per cent of the total warming.¹⁴⁵ This amounts to 0.3 °C for a 2 °C rise in temperature (our own calculation). The uncertainty is two-sided, but from a planning perspective, the branch pointing towards further warming is the more costly one (G.5).

The cooling following overshoot is even slower and more uncertain. According to the UNEP report, a net carbon dioxide removal of around 220 billion tonnes is required to achieve a 0.1 °C reduction in temperature. A net removal of 10 billion tonnes per year – roughly a quarter of current emissions – would result in a cooling of only about 0.05 °C per decade. Reversing a decade's worth of warming at the current rate would therefore take at least half a century. Permanent land-based removal has amounted to around 2 billion tonnes per year over the past decade. According to the report, even under optimistic assumptions, a cooling of no more than a few tenths of a degree can be expected this century, and it is not certain that the removal would cool the atmosphere by the same amount that the equivalent volume of emissions has warmed it.¹⁴⁵

Looking ahead to 2050, this gives rise to three planning implications.

- 1 Warming will continue until 2050 on current trajectories, as the world will not reach net zero by then (VII.2).
- 2 A halt in warming after net-zero is the best estimate, but not a guarantee. The design of long-lived facilities cannot therefore count on this as a saving.
- 3 Adaptation must be scaled to the expected peak level, not to a subsequent cooling trend. The UNEP report also recommends that adaptation decisions be based on the risks between exceeding 1.5 °C and the expected peak, as a reversal would take decades.

VII.4 Europe and the Carpathian Basin by 2050

According to the Copernicus and WMO European climate report, Europe has been warming twice as fast as the global average since the 1980s. The rate has been around 0.56 °C per decade since the mid-1990s. Within the continent, Eastern and South-Eastern Europe, as well as parts of Central Europe, are warming the fastest.¹⁴⁶ The ‘twofold’ ratio cannot be used as a multiplier, because the European figure applies only to land, while the global figure covers both land and ocean, and land is warming faster than the ocean even in the global average (VI.6).

Domestic measurements paint a similar picture. The annual mean temperature has risen from 9.9 °C in the 1971–1980 period to 12.0 °C for 2021–2025, while the summer mean has risen from 19.1 °C to 22.4 °C (II.1). The official Hungarian projection, HungaroMet’s KLIMADAT service, projects a national average warming of 1.2–1.7 °C for the period 2021–2050 compared with the 1971–2000 average (the national average of the minimum and maximum values per grid point across the four runs; median 1.3 °C).¹¹ According to the same service, using the same reference period, the observed 30-year average rose by 1.0 °C between 1971–2000 and 1996–2025. The median of the projections only reaches this level in the 2011–2040 period: on an annual average, the projection lags behind the observed data by around 15 years; in summer, it lags by around 24 years; while in winter, it leads the observed data (H.2). Taken together with the minimum rule, this indicates that the official 2050 annual and summer temperature values should be treated as lower estimates; however, this does not apply to winter values.

Domestic sources differ regarding summer precipitation. Previous domestic summaries suggested a likely decrease in summer precipitation.

According to HungaroMet's 2024 assessment, however, the direction of the change is uncertain, and a decrease is only likely in the event of high emissions.¹⁴⁷ Measurements show a decrease: precipitation in the summer half-year fell from 367 mm in the 1991–2020 period to 312 mm for 2021–2025. This change cannot yet be statistically confirmed as a level shift (III.1). Planning should therefore treat the summer decline as the direction of risk. This is our conclusion drawn from the measurements, which does not resolve the uncertainty of the official projection. We are reporting this because the cost of error is greater in the direction of drought (G.5).

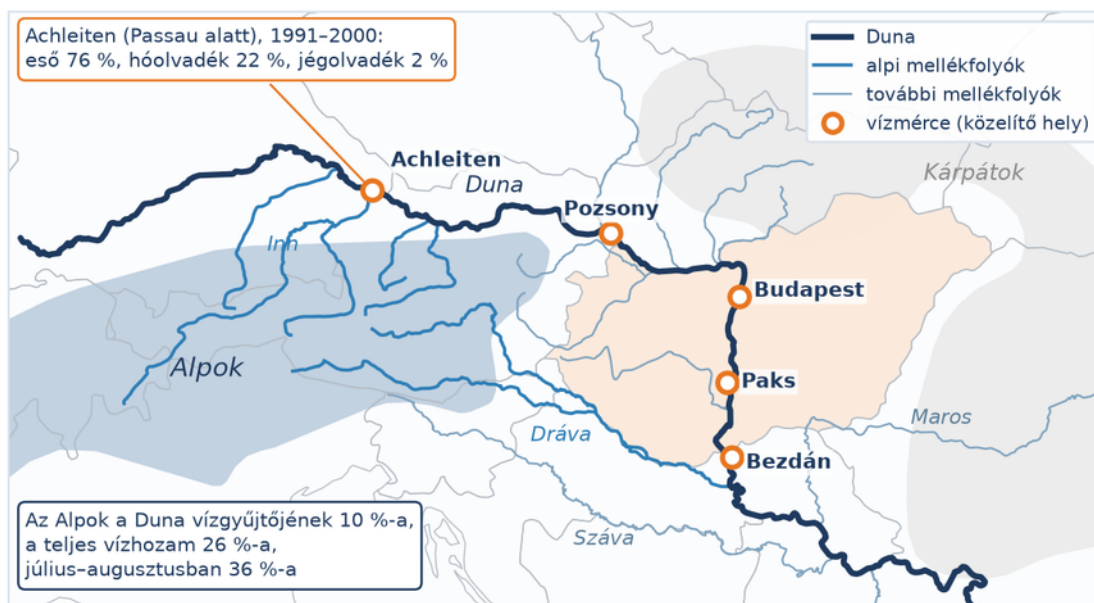
Two institutional sources provide a domestic benchmark for drought. According to the OECD's 2026 report on water governance – based on a 2014 domestic study using the previous generation of models – the risk of drought will increase by 10–30 per cent across 96 per cent of the Great Plain between 2021 and 2050. According to the Hungarian National Bank's 2026 report, in three out of four years between 2021 and 2024, at least 70 per cent of the country was affected by drought, while between 2000 and 2020 this occurred a total of seven times.¹⁴⁸ The OECD notes in the same report that 96 per cent of Hungary's freshwater supply comes from beyond its borders. The future of the country's water supply therefore depends largely on the climate and water use of upstream countries (VII.5).

VII.5 The Danube catchment: the diminishing role of the Alps as a water reservoir

Below the mouth of the Inn, the Danube is an Alpine-type river, with its summer water abundance supplied by Alpine tributaries. The Alps account for 10 per cent of the Danube's total catchment area, yet they contribute 26 per cent of its discharge, rising to 36 per cent in July–August (Map VII/4). The mountain range acts as a water reservoir, retaining winter precipitation in the form of snow and ice, and releasing it in spring and summer. According to a hydrological model calculation at the Achleiten gauging station downstream of Passau, 76 per cent of the annual runoff in the period 1991–2000 came from rain, 22 per cent from snowmelt and 2 per cent from ice melt.¹⁴⁹

MAP VII/4

The upper catchment of the Danube: the Alps account for one-tenth of the catchment area and more than one-third of the summer discharge.



Illustrative map showing the main Alpine tributaries and the gauges mentioned in the text.

SOURCE Hydrological Atlas of Switzerland, Plate 6.4; Weber et al. (2010). Map base: Natural Earth; own compilation.

NOTE The locations of the gauging stations are approximate. The Alpine contribution refers to the entire Danube catchment; we were unable to find separate, reliable contribution data for the Hungarian section. The Hungarian section of the Tisza is not included in the base map.

This supply is dwindling, and faster than the models predict. According to model calculations, the volume of the Alps' glaciers will decrease by 47–52 per cent by 2050 compared with 2017 levels, essentially regardless of the emissions trajectory. More than a third of today's ice volume will be lost by 2050 even if the climate remains as it is today. At Alpine stations, average snow depth decreased by 8.4 per cent per decade between 1971 and 2019.¹⁵⁰

Measurements are already ahead of this trend. According to the report published by the Swiss Glacier Monitoring Network on 1 October 2026, more than 5 per cent of Switzerland's ice volume disappeared in the 2025/26 season, with glaciers losing an average of 2.5–4 metres in thickness, and up to 10 metres in places along the glacier tongues. This is the second-largest annual loss following the record year of 2022, and several major glaciers (Aletsch, Rhône, Allalin, Clariden) recorded the greatest melt in their respective measurement histories. Between 2022 and 2026, nearly 20 per cent of Switzerland's ice melted over the course of five years.¹⁵⁰ The projected loss of 47–52 per cent by 2050, spread over 33 years, equates to 1.4–1.6 per cent of the 2017 volume per year, or 1.9–2.2

per cent per year relative to the ice volume remaining at any given time; the rate measured since 2022 is roughly double this. A single hot year does not establish a trend, and 2024 was more favourable than this; however, the direction of the trend is clear, so the 2050 model value should be regarded here too as a lower estimate, not an expected scenario (H.2). Furthermore, the Danube catchment is not fed by the large Valais glaciers, but by the smaller, lower-lying Austrian and Engadine glaciers of the Inn, Salzach, Enns and Drava, which are melting proportionally faster than the Swiss average. No comprehensive volume balance is available for this sub-basin; consequently, only the trend can be deduced from the Swiss data, not the extent.

The level of warming matters little up to 2050, but becomes crucial thereafter. According to a global study from 2025, around 39 per cent of glacier mass will be lost even if the climate remains at current levels, and every further 0.1 °C will result in roughly a further 2 per cent loss of ice. In the Alps, the authors report that current warming will, in the long term, result in the loss of half the ice, and that with sustained warming of 1.5 °C, 30 per cent of the ice will remain; at 2 °C, 15 per cent; and at 3 °C, around 5 per cent. These figures refer to the point at which equilibrium is reached, not to the year 2050.²³² According to another study, with a temperature rise of 2.7 °C, the glaciers of Central Europe will have almost completely disappeared by the end of the century.²³³

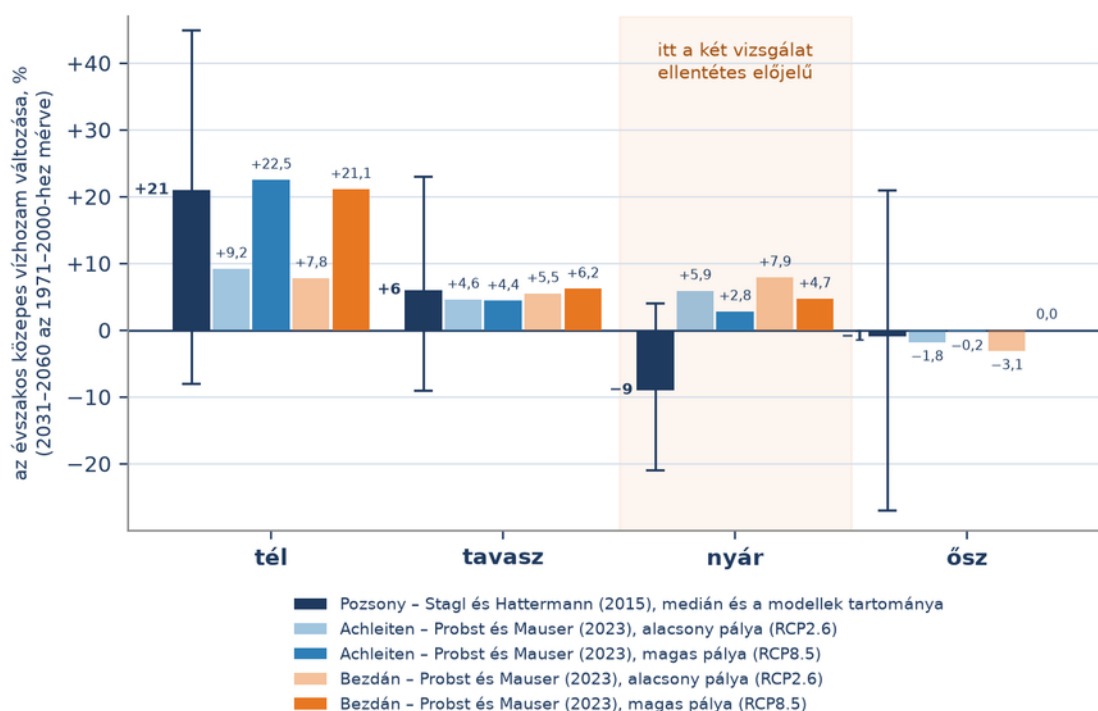
This gives rise to three conclusions for planning purposes, all of which are our own. (1) By 2050, there is little difference between the 2 °C and 2.5 °C scenarios in terms of the Danube's ice reserves, because most of the ice will melt in any case due to the warming that has already occurred, and the measured rate is approximately twice that projected. (2) After 2050, the temperature level will be decisive: in the long term, at 2 °C a fraction of the Alpine ice will remain, while at 3 °C it will virtually disappear, and with it the glacier-fed flow reserve for hot, dry summers. (3) Water abstraction, cooling water and shipping facilities that will remain in operation after 2050 must be designed for the Danube, which, at a 2.5 °C stress level, will have significantly reduced ice reserves.

This has two consequences for water flow, and the certainty of the two differs. Studies agree on the seasonal shift: for the period 2031–2060, they predict a 7–22.5 per cent increase in winter water flow, while the annual average will not decrease. According to the more recent study, high-water events will also become more frequent. With regard to summer water flow, however, the two main model studies arrive at conflicting results

(Figure VII/5). One predicts a 9 per cent decrease at Bratislava, and a 14 per cent decrease in August; the models' range is between -21 and +4 per cent. The other, more recent study indicates a 3–8 per cent increase at Achleiten and Bezdán, and suggests that low flows will become less frequent on this stretch in an average year.¹⁵¹ A lower average summer water flow is therefore not a substantiated expectation by 2050, but a scenario to be examined via a stress test within the risk framework.

FIGURE VII/5

According to the median values of the studies, the Danube's winter discharge increases; the sign of the change in summer discharge is disputed.



Change in seasonal mean discharge, %; 2031–2060 compared with the period 1971–2000.

SOURCE Stagl and Hattermann (2015), Table 2; Probst and Mauser (2023), Table 3.

NOTE On the Bratislava plots, the line indicates the minimum and maximum values from the models. The two studies use different model generations and different water gauges; therefore, the discrepancy cannot be resolved in favour of either.

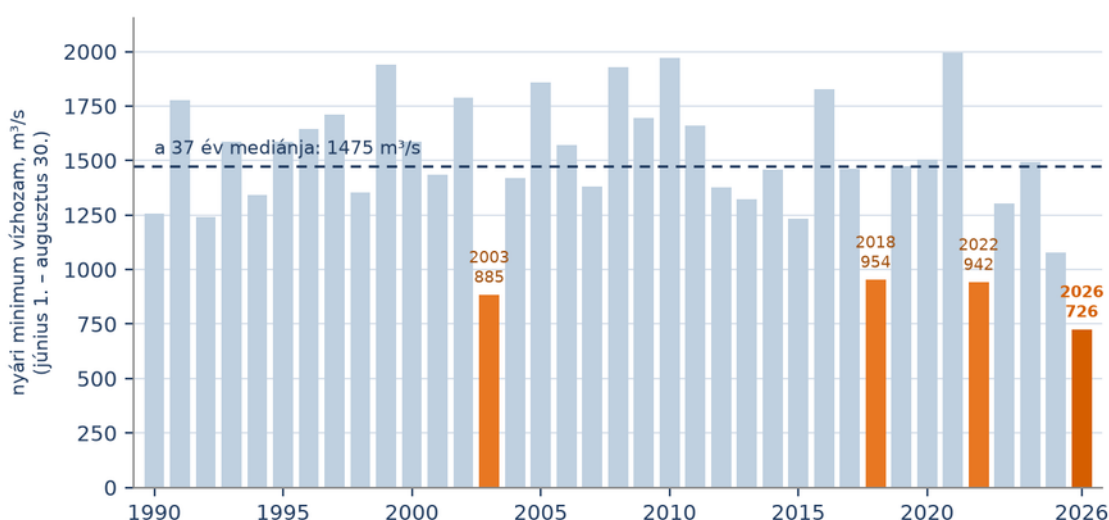
The small annual proportion of meltwater is misleading. During dry, hot summers, when rainfall is scarce, glaciers provide the reserve. In the exceptional year of 2003, 9 per cent of the Lower Danube's water flow in September came from glacial meltwater, even though only 0.06 per cent of the catchment area was glaciated. According to the source, the retreat of glaciers exacerbates summer water shortages even in catchments with little glaciation.¹⁴⁹ It follows that the water flow in an average year changes very little, while that in the driest summers may decrease. Without snow and ice reserves, water flow follows rainfall more directly,

that is, the weather conditions of individual years. We deduce this qualitatively from glacier and snow studies; we do not provide a quantitative estimate, and we report it because planning is based on extreme years (G.5).

The summer of 2026 demonstrated the magnitude of an extreme year. At Paks, the minimum summer water flow was 726 m³/s, the lowest summer value in the thirty-seven-year record, and half the median across years (1,475 m³/s) (Figure VII/6). On 8 October, the daily average fell to 613 m³/s (preliminary, operational data; IX.5). This low flow led to the nuclear power station reducing its output (IV.4). This is a single year, from which no trend can be read, and we have not examined the role of Alpine snow and ice reserves in it.¹⁵²

FIGURE VII/6

The summer minimum flow of the Danube at Paks in 2026 was the lowest value in the 37-year series.



Discharge, m³/s. Lowest daily average for the year in the 1 June–30 August window, 1990–2026.

SOURCE Own calculations based on the official hydrological time series (National Water Authority, Paks).

NOTE Descriptive figure, without trend test. The window must be specified: the minimums calculated for the whole year differ. The water flow is subject to regulation (the operation of upstream barrages partially smooths out the daily average).

The model results are less favourable for rivers in the domestic and Carpathian catchment areas. The latest study predicts a 9 per cent reduction in autumn water flow on the Tisza and a 3–14 per cent reduction in summer and autumn water flow on the Maros for the period 2031–2060, under both emission scenarios examined.¹⁵¹ Due to 96 per cent external dependence, water use in upstream countries also forms part of the domestic risk: in years of drought, water demand increases there too. The sources do not provide a quantitative estimate of this.

For planning purposes, the Danube will have three implications up to 2050.

- 1 In winter and early spring, there is more water and the flood risk is greater.
- 2 In summer, the average trend is uncertain, and a worsening of extreme low flows is possible.
- 3 In the planning of cooling water, navigation and drinking water supplies, the year 2026 is the measured baseline case for the stress test.

VII.6 Tipping points affecting Hungary

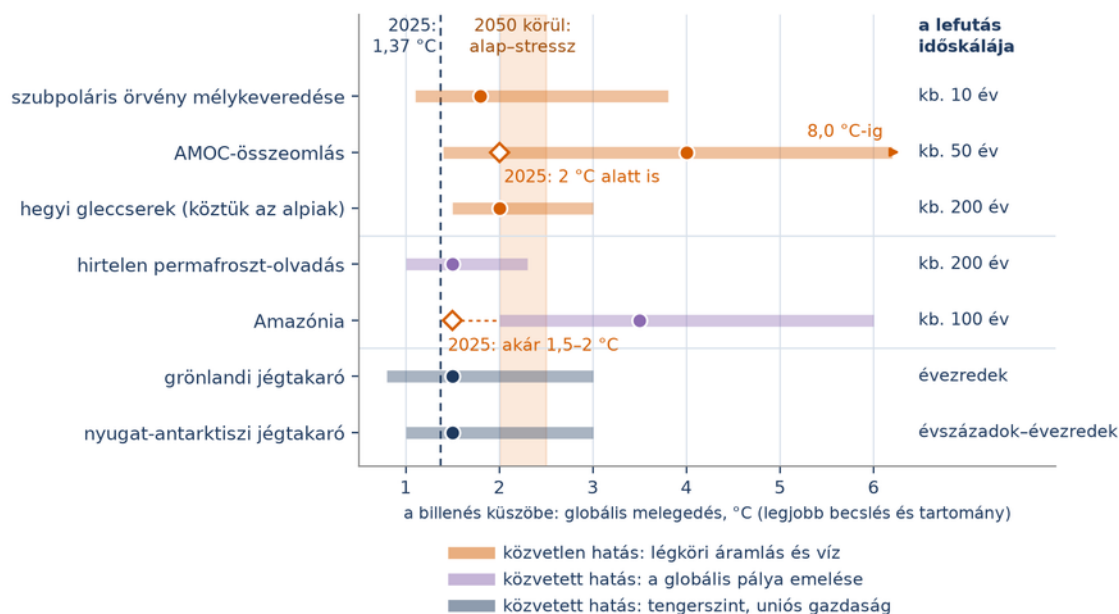
A tipping point is defined as the threshold beyond which an element of the climate system enters a new state through self-reinforcing processes. The change continues even after the triggering effect has ceased. From a planning perspective, two distinct time points can be identified: the trigger, when the system crosses the threshold, and the run-out phase, until the new state is established. Decades or centuries may elapse between the two.

The tipping elements are all located outside Hungary's borders. Their effects reach the country in three ways (Figure VII/7).

- 1 Changes in the Atlantic Deep Current, the subpolar gyre and Alpine glaciers have a direct impact via atmospheric circulation and river flow regimes.
- 2 The thawing of permafrost and the transformation of the Amazon exert an influence via the global carbon balance, raising the warming trajectory.
- 3 The melting of the two major ice sheets has an impact via sea level rise and the EU economy.

FIGURE VII/7

Of the seven tipping points affecting Hungary, the threshold estimates for five lie within or below the range between the 2050 planning baseline and the stress level.



Tipping point: global warming, °C. Point: best estimate; range: range of estimates; time scale of the run-out on the right-hand side.

SOURCE Armstrong McKay et al. (2022), Table 1; Lenton et al. (2025).

NOTE The thresholds are derived from an expert review of the literature, not from a single model; the wide range indicates uncertainty in our understanding. The empty diamonds indicate lower threshold estimates from the 2025 assessment (Atlantic deep-ocean circulation: even below 2 °C; Amazon: as low as 1.5–2 °C). For permafrost, the threshold for sudden thawing is shown; that for the collapse of boreal permafrost is 4 °C.

Based on the most frequently cited assessments of these thresholds, the best estimate for five of the seven elements affecting Hungary falls within, or below, the 2–2.5 °C range between the 2050 planning baseline and the stress level. These are deep mixing in the subpolar gyre (1.8 °C), mountain glaciers (2.0 °C), abrupt permafrost thaw (1.5 °C) and the two ice sheets (1.5 °C). Alpine glaciers form part of the mountain glaciers group. According to the 2025 international assessment, the Atlantic deep circulation could collapse even at temperatures below 2 °C, while the transformation of the Amazon could begin as early as 1.5–2 °C; the best estimates from 2022 were 4 and 3.5 °C respectively. According to this, the number of elements falling within or below this range could be more than five.¹⁵³ The retreat of ice sheets and permafrost is a process spanning centuries to millennia. For these, the risk up to 2050 is the triggering, while the consequences will be borne by future generations.

The Atlantic deep-water current (Atlantic Meridional Overturning Circulation, AMOC) transports warm water northwards at the surface, which then cools and sinks near Greenland. The subpolar gyre is the northern

part of the Atlantic Ocean, comprising the Labrador Sea and the Irminger Sea, where part of this downwelling (deep mixing) takes place. A comparison of the sources yields four findings for the 2050 horizon.¹⁵⁴

- 1 The AMOC will weaken in the 21st century – on this point the IPCC and the models agree – but the extent of this weakening expected by 2050 is disputed.
- 2 A complete collapse by 2050 is not the central scenario, but cannot be ruled out.
- 3 A collapse occurring at a later date may be triggered before 2050; in other words, it is a realistic possibility, but not the central scenario. This is our own assessment, based on the fact that the only observation-based statistical estimate places the collapse between 2037 and 2109, while the majority of models do not show a collapse within this century.
- 4 A sudden cessation of deep mixing in the subpolar gyre is shown to carry a risk of up to 36.4 per cent in the best models of the latest generation, and would occur on a timescale of decades. In our view, this is possible by 2050.

The literature from 2025–2026 clarifies this picture in two respects. According to a study based on model runs extended to 2300, the North Atlantic Overturning Circulation will cease in all models on the very high emissions pathway and in some models on the medium and low pathways, but only after 2100; this shutdown will be preceded by the collapse of North Atlantic deep mixing in the middle of the century. Deep mixing has declined in all observational datasets over the past 5–10 years, although the authors note that this could also be due to natural variability.²³⁴ By the year 2050, therefore, the shutdown of deep mixing is the realistic risk, not a complete shutdown of the overturning circulation. However, there is no consensus on whether the AMOC is already weakening: a reconstruction based on atmosphere–ocean heat exchange found no decadal weakening between 1963 and 2017, and demonstrated that the surface temperature fingerprint underlying the above statistical estimate for 2037–2109 does not reliably reflect changes in the AMOC.²³⁵ The literature currently does not resolve the debate between these two approaches, so we shall not take a stance on this matter here either.

There is no impact assessment specifically relating to the Carpathian Basin. Three domestic implications can be derived from the European modelling results. These are our own conclusions, and we are presenting

them because the current domestic risk assessment does not take any of them into account.

- 1 The experiments examined do not reverse the direction of domestic warming. The significant cooling values relate to north-western Europe and the state following a complete collapse. There, on a warming trajectory of around 2 °C, the balance may shift towards cooling, but not on a 4 °C trajectory. The collapse would intensify cold extremes even alongside warming. In the combined scenario, summers cool only slightly, while winters may turn extremely cold, and interannual variability increases.¹⁵⁵
- 2 Summer drying would intensify, which would add to domestic evaporation pressure (II.2).
- 3 In one model experiment, winter precipitation in Central Europe decreases. This would hinder winter groundwater recharge (III.1).¹⁵⁵

In planning, the AMOC risk therefore justifies the combined assessment of winter and summer extremes (II.4), but does not render preparations for warming unnecessary.

The risk of tipping also increases with the extent of overshoot, rising with every additional 0.1 °C, and accelerating sharply above a 2 °C peak. According to model calculations, under current policies, there is a 45 per cent (23–71) risk that at least one of the four main tipping elements will tip by 2300. This risk persists even if temperatures subsequently fall back below 1.5 °C.¹⁵⁶ Early warning is also possible. In one model, a sudden northward shift in the path of the Gulf Stream precedes the collapse by around 25 years, and this signal can be tracked by satellite.

In reality, accelerating warming and tipping points cannot be separated; the planning levels treat them separately solely for analytical reasons. The major tipping elements – ice sheets, permafrost, the Amazon – will, according to our own assessment, raise global temperatures only slightly by 2050; their impact will primarily widen the range of possible trajectories after 2050. Smaller systems, however, react quickly: according to the 2025 international assessment, the threshold for warm-water coral reefs is around 1.2 °C, meaning that current warming has already exceeded it.¹⁵³ A strong El Niño, superimposed on the warming trend, could bring forward the crossing of these thresholds; the literature is divided on whether global warming itself intensifies El Niño events, and so far no one has attributed the strength of the 2026 event to global warming.²³⁶ Our own conclusion is that the 2 °C planning baseline is a more optimist-

ic than a cautious assumption, and even this implies summers in the Carpathian Basin that today rank among the warmest (VII.1).

VII.7 How external impacts reach the country: five channels up to 2050

The risks associated with 2050 are not merely physical. Climate impacts reach the country via economic and social systems, and these systems may themselves be in crisis for other reasons. The general patterns of mutually reinforcing crises are discussed in section VIII.3; this section lists the domestic channels. From Hungary's perspective, five channels can be identified. This list has been compiled by us; the sources for the items are cited in the footnotes.¹⁵⁷

- 1 Water from across the border. Ninety-six per cent of water resources come from abroad; therefore, droughts and water use in upstream countries directly affect domestic supplies (VII.5).
- 2 Drought and food prices. The 2022 drought caused crop losses of around 2.4 billion euros across six major arable crops (V.2). The 2022 European summer heatwave increased food inflation in Europe by 0.43–0.93 percentage points. Without effective adaptation, global food production could fall by as much as 14 per cent by 2050.
- 3 Fertilisers, energy and geopolitics. Global trade in fertilisers and liquefied natural gas (LNG) is concentrated on a few maritime routes: in 2024, up to 30 per cent of fertiliser trade and around 20 per cent of LNG trade passed through the Strait of Hormuz. Any disruption there would affect both the energy and food systems simultaneously.
- 4 Financial system. The Hungarian National Bank's 2025 climate stress test examined transition risk; the 2026 report does not include a physical risk stress test. Banks' non-green agricultural financing (domestic corporate loans and securities) amounts to 1,090 billion forints. The MNB classifies this under transition risk; there is no physical risk classification for this category.

5 Population movements. Extreme weather is an increasingly significant driver of forced migration, but such movements predominantly take place within countries and regions; the IPCC states this with a high degree of confidence.²³⁷ The World Bank estimates that by 2050, up to 216 million people across six regions could become internal climate migrants; with substantial emissions reductions, this figure would be around 80 per cent lower.²³⁸ The impact of the environment on migration is strongest in agriculture-dependent, middle-income countries.²³⁹ There are no official EU estimates of climate migration pressure towards the European Union; the most frequently cited, though controversial, study projects a 28–188 per cent increase in the number of asylum applications by the end of the century, depending on the extent of global warming.²⁴⁰ Hungary may be indirectly affected by this via transit routes. Within the country, the Homokhátság region is the closest example: its population has been declining and ageing for decades, and according to a 2017 study, without intervention, these adverse trends will become irreversible within a few decades. Research primarily cites educational and developmental disadvantages as the causes of emigration, while treating drying as an economic and environmental constraint rather than an identified cause.²⁴¹ Our own hypothesis is that drying accelerates emigration; this has not yet been confirmed by any domestic study, and the official population projection is also outdated for the purposes of investigating this (IV.2).

From a risk management perspective, the key question is whether these channels open up simultaneously. They share a common root cause, as the same hot, dry summer simultaneously reduces crop yields, river flows and the cooling water available to power stations, while increasing demand for electricity and the burden on the healthcare system. The individual risks cannot therefore be treated as independent events (VIII.3), as the probability of their simultaneous occurrence is greater than would be suggested by the assumption of independence. This is our own conclusion, based on the common underlying cause, without a quantitative estimate. The summer of 2026 illustrated this situation: a record-breaking dry spell during the growing season, record-low flows in the Danube and the output reduction at the nuclear power station all occurred simultaneously (II.2, IV.4).

According to the European Environment Agency's 2024 risk assessment, existing financial stress tests are likely to underestimate complex and cascading risks. The assessment does not classify Central and Eastern Europe as a risk hotspot, but notes that regions with lower adaptive capa-

city are concentrated in Central and Eastern Europe and parts of Southern Europe.¹⁵⁷ The absence of a classification should therefore not be interpreted as indicating low risk, particularly as the national vulnerability data are out of date (IV.2). At the decision-making level, these channels are linked by the risk of derailment (VIII.3).

VII.8 Risk assessment and planning outlook for 2050

Figure VII/8 summarises the findings of this chapter in a risk balance sheet. Each row identifies a risk, with a verbal classification of its likelihood of occurrence, its domestic impact and its role in planning. The balance sheet does not quantify the magnitude of the domestic impact, as there are no recent official domestic estimates for this (V.1).

FIGURE VII/8

Risk assessment up to 2050: what to design for, what to test via stress tests, and what to monitor.

Kockázat 2050-ig	Bekövetkezés	Mit érint itthon	Tervezési szerep
A globális melegedés eléri a 2 °C-ot	valószínű	minden hazai mutató háttere: hőség, párolgásigény, vízmérleg	tervezési alap
A globális melegedés eléri a 2,5 °C-ot	lehetséges	gyakoribb összetett stresszév (VIII.6, C sáv)	kötelező stresszpróba
A globális melegedés eléri a 3 °C-ot	kevésbé valószínű nem zárható ki	a 2070 utánig működő létesítmények méretezése	történetiszál, korai jelzés
A melegedés 1,8 °C körül tetőzik	lehetséges kedvező eset: minden vállalat teljesül	-	megtakarításként nem számolható el
A melegedés 1,5–1,6 °C-on megáll	kevésbé valószínű kedvező szélső eset	-	megtakarításként nem számolható el
A melegedés a nettó zero után sem áll meg	lehetséges a nyelők gyengülése	hosszú élettartamú létesítmények	megtakarításként nem számolható el
A hazai hőség és párolgásigény a hivatalos projekció fölött alakul	valószínű	egészség, mezőgazdaság, vízkészlet	tervezési alap
A Duna vízjárása ártrendeződik: több téli víz, kisebb alpi tartalék nyáron	valószínű	hűtővíz, hajózás, ivóvíz, öntözés	tervezési alap
A Duna nyári kisvizei súlyosbodnak	lehetséges a modellek megosztottak	atomerőművi hűtés, hajózás	kötelező stresszpróba
A Maros nyári-őszi és a Tisza őszi vízhozama csökken	lehetséges egy vizsgálat szerint	alföldi öntözés, hűtővíz, ökológiai vízigény	kötelező stresszpróba
A szubpoláris örvény mélykeveredése leáll	lehetséges	téli és nyári szélsőségek, nagyobb változékonyság	történetiszál, korai jelzés
Az AMOC összeomlása kiváltódik (lefutása 2050 után)	lehetséges	Európa időjárása, az uniós gazdaság	történetiszál, korai jelzés
A jégtagarók vagy a permafroszt billenése kiváltódik	lehetséges lefutása évszázados	tengerszint, globális szénmérleg, uniós gazdaság	történetiszál, korai jelzés
Egyidejű sokk: aszály, hőség, kisvíz és külső ár- vagy ellátási zavar	lehetséges közös kiváltó ok	költségvetés, élelmiszerárak, energiaellátás	kötelező stresszpróba
A nemzetközi kibocsátáscsökkentés megakad	lehetséges	a fenti sorokat a stresszszint felé tolja	figyelendő jelző

The classification is our own assessment based on the sources cited in this chapter; it is not a calculated probability.

SOURCE Compiled by the authors based on the sources in VII.1–VII.7.

NOTE Likely: according to the majority of sources, it is more likely to occur than not. Possible: according to well-founded sources, it is realistic but not the central outcome. Unlikely: requires the concurrence of several conditions, but cannot be ruled out. The rows are not independent of one another (VII.7, VIII.3).

Official Hungarian geospatial and climate products provide projections for the 2021–2050 and 2071–2100 timeframes, based on two emission scenarios (RCP4.5 and RCP8.5), using regional models from the previous model generation. There are currently no more recent official products, and domestic planning documents refer to these for the year 2050.

In our view, the minimum rule set out in [H.2](#)—on those indicators where it has been verified, namely temperature, the number of days reaching 30 °C, spring frost and the vapour pressure deficit—will remain valid for 2050 as well. If the discrepancy between the observed trend and the model range is persistent, the difference increases over a longer time frame – this is an extrapolation, not a measured result. According to current evidence, planning for the midpoint of the official range for these indicators by 2050 constitutes an underestimation. The justifiable approach is to design for the upper end of the range, treating the lower end of the range as a lower limit rather than a conservative case, with the observed value serving as the planning minimum. However, the minimum rule cannot be applied to the duration of dry spells and the level of precipitation intensity ([II.2](#), [II.4](#)), as the model does not underestimate these variables.

Four findings based on domestic indicators appear to be robust up to 2050, albeit with varying degrees of certainty. These complement the domestic rows in Figure VII/8:

- A further increase in heat stress is likely, with the lower limit of the increase being the lower end of the model range.
- The seasonal shift in precipitation – with a surplus in winter and a deficit in summer – appears stronger in the observations than indicated, but no clear shift in the precipitation series can yet be detected ([III.1](#)). This is the weakest of the four findings.
- Extrapolating the increase in the vapour pressure deficit from the observed trend indicates a greater risk than the projection suggests – and the projection is currently not usable for this variable.
- Winter groundwater recharge only begins above a certain precipitation level ([III.1](#)). This is partly due to soil and land-use characteristics; therefore, we consider that the effect of retention up to 2050 will largely depend on land-use decisions.

According to [G.5](#), in planning, inaction is the more costly mistake. By the 2050 horizon, this asymmetry is more pronounced than on the decadal horizon. The damage caused by the triggering of tipping points and by overshooting is irreversible, whereas the cost of unnecessary preparedness is a one-off and visible expense. Moreover, much of the preparation is justified for other reasons as well, since the combined assessment of winter and summer extremes and the management of external dependencies on water supplies form part of the domestic risk profile, even independently of the Atlantic deep-water current. This is our own assess-

ment, and we are sharing it because the argument that ‘it is uncertain, so we are not planning for it’ does not apply to irreversible risks.

What cannot be predicted for 2050: the evolution of atmospheric circulation (II.5), the sequence of individual years, the magnitude of economic damage based on Hungarian data, and the state of the Atlantic deep-ocean current in 2050.

VIII

The need for a change in perspective: the importance of correctly understanding non-linear changes, interlinked risks and early warning signs

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KEY FINDINGS

Thresholds	The average changes slowly, while the frequency of events above the threshold changes rapidly. The national annual mean temperature rose by 1.2 °C between 1991–2020 and 2021–2025, while the number of extremely hot days tripled from 2.8 to 8.5 per year over the same periods. The frequency of events above the threshold should therefore be used as the basis for dimensioning rather than the average.
Two speeds	The crisis arises from the convergence of slow erosion and a sudden turning point. Slow deterioration is not spectacular in any given year, but in the event of a turning point, the most recent record may be significantly broken.
Interconnection	If risks are linked by a common cause, they cannot be treated as independent events, because the probability of their joint occurrence is greater than that implied by the assumption of independence. The damage may also weaken the ability to prevent further harm: this is known as the risk of derailment.
Cognitive biases	According to the literature, planning often overlooks important patterns due to distorted perceptions of normality, a belief in permanence, and compartmentalisation.
	The <i>correct approach</i> . The way to reduce risk is to identify the reasonable worst-case scenario, apply a reverse stress test, establish decision points in advance, build up reserves and extend preparedness to society as a whole. Three possible scenarios and twelve warning signs provide a framework for planning for the coming decade.

The previous chapters have shown what has changed and by how much. This chapter takes a practical approach to how one should consider the measured changes during the planning process. The same data can lead to completely different decisions depending on whether the planner assumes steady, independent changes, or takes into account thresholds, interlinked effects and sudden shifts.

The lesson from British risk assessment practice (G.3) is that, in the case of chronic risk, a probabilistic framework alone is insufficient. The first five sections of this chapter (VIII.1–VIII.5) address this shortcoming. They explain why climate change is not linear, how risks are interlinked, and why it is difficult to manage this using conventional thinking and planning methods, before offering practical solutions. The final three sec-

tions (VIII.6–VIII.8) apply this approach to the coming decade and, on this basis, present three possible scenarios, twelve warning signs, and the conditions under which the conclusions might be refuted.

The theoretical propositions are drawn from the literature cited in the notes, while the domestic examples are taken from the measurements in the preceding chapters. The linking of the two—that is, determining which theoretical pattern a domestic measurement exhibits—is largely a conclusion of the analysis, and where this is not obvious, we indicate this separately.

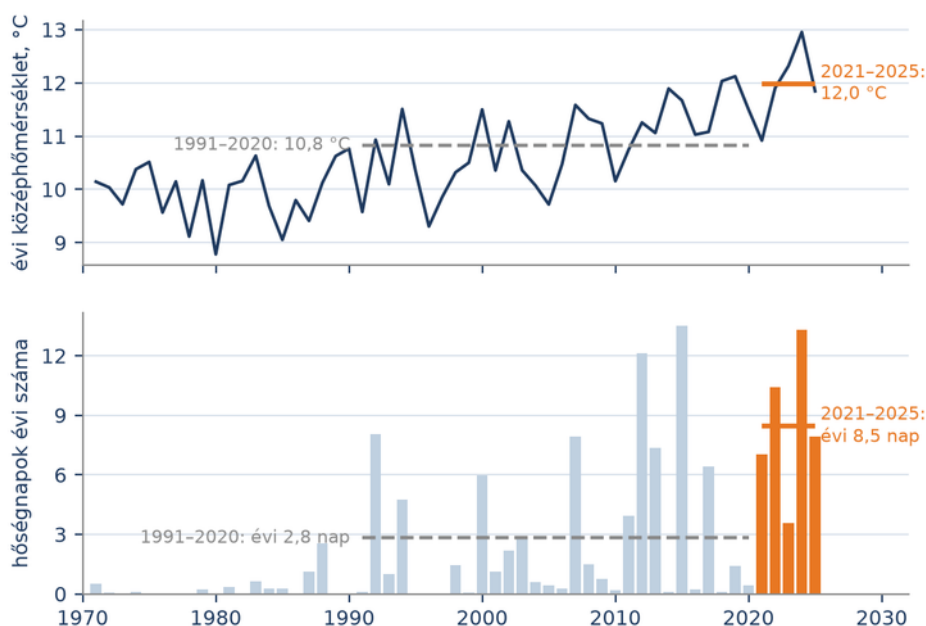
VIII.1 Why change is not a straight line

One of the unspoken basic assumptions of planning today is that tomorrow will be much the same as yesterday, only a little warmer. However, this assumption fails on four counts.

The effect of thresholds: the average moves slowly, while the frequency above the threshold rises rapidly. If a distribution as a whole shifts slightly, the frequency of events at its extremes increases much more rapidly. Thus, the number of extremely hot days in the years 2021–2025 was 8.5 per year, compared with 2.8 in the period 1991–2020 – that is, three times as many (II.1, Figure VIII/1). However, the damage occurs on days when temperatures exceed the threshold, as the burden on the healthcare system, the cooling water constraints on power stations and heat stress on plants all arise when a threshold is crossed. Moreover, in a warming climate, records are broken by ever-larger margins, and the likelihood of events significantly exceeding the record increases (VI.4).¹⁵⁸

FIGURE VIII/1

The average temperature has risen by 1.2 °C, and the number of extremely hot days has tripled.



Top: national annual mean temperature, °C. Bottom: annual number of extremely hot days (daily maximum ≥ 35 °C), national grid average. 1971–2025; dotted line: average for the period 1991–2020; orange line: average for the period 2021–2025.

SOURCE Own calculations based on official homogenised national time series (grid average), using the same data as in Figure II/7.

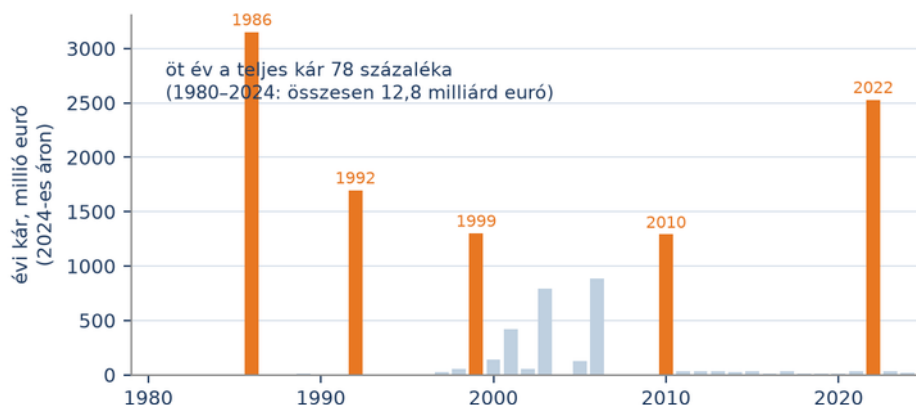
NOTE The 1991–2020 average is 10.8 °C and 2.8 extremely hot days per year; the 2021–2025 average is 12.0 °C and 8.5 extremely hot days per year; the unrounded temperature difference is 1.16 °C. The same shift appears as a 1.2 °C change in the average and a threefold increase above the threshold.

Accelerating damage. Climate-related damage increases at an accelerating rate as warming progresses, because warming exceeds physiological, tolerance and design limits (G.5). On an upward-curving damage curve, designing for the mean value consistently underestimates the expected damage. The economic literature makes even stronger claims than this. If the probability of the worst-case outcomes decreases only slowly as the severity of the outcome increases, rare catastrophic events may determine the expected cost. This effect is not offset even by discounting future losses.¹⁵⁹ The extent to which this condition holds true in reality is disputed. From a planning perspective, this implies that rare, severe outcomes cannot be disregarded simply because they are rare. The domestic damage history shows the same pattern, as between 1980 and 2024, 78 per cent of the damage caused by weather and climate extremes occurred in just five years, with the median annual damage amounting to 14 million euros (V.2, Figure VIII/2). Expected losses are therefore determined by a few rare years in Hungary as well. This does not validate

Weitzman's condition; it merely shows that the average year is a poor basis for dimensioning – this is the interpretation of the analysis.

FIGURE VIII/2

Damage occurs in a few bad years: five years accounted for 78 per cent of the damage over the 45-year period.



Annual damage caused by weather and climate extremes in Hungary, in millions of euros at 2024 prices, 1980–2024. The five years with the highest damage are highlighted.

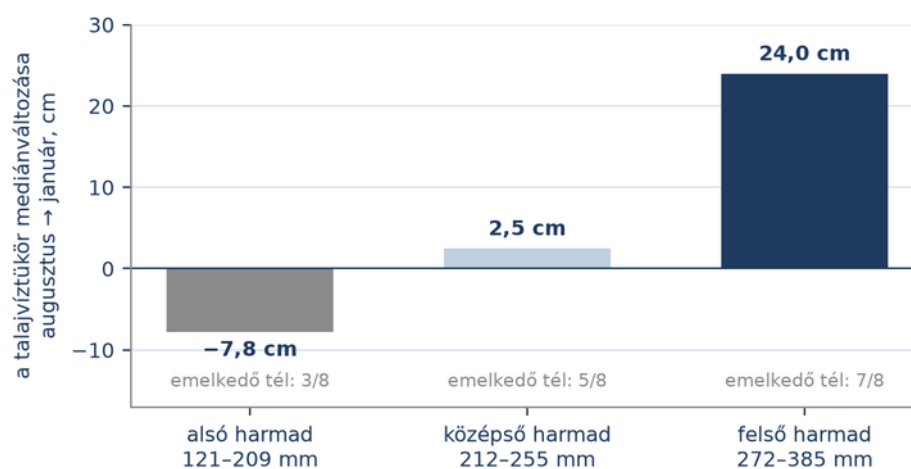
SOURCE European Environment Agency, CATDAT-based damage series (fourth-quarter 2025 revision), national annual breakdown; own visualisation.

NOTE The five years with the highest losses were 1986, 2022, 1992, 1999 and 2010; together, they accounted for 77.8 per cent of the total losses of approximately 12.8 billion euros. The mortality data in this series is incomplete, and only a small proportion of the losses was insured (V.2). The low or zero values for the 1980s and 1990s may partly reflect more incomplete early records; therefore, the degree of concentration may be somewhat overestimated (own assessment).

Inflow is also threshold-dependent. Groundwater does not respond proportionally to precipitation during the winter half-year (III.1). In the Homokhátság monitoring network, in the lowest third of winters the median groundwater level fell by 7.8 cm compared with the end of summer; in the middle third, it rose by 2.5 cm; and in the upper third, it rose by 24 cm (Figure VIII/3). The water table therefore only replenishes during a few winters with abundant rainfall, and a single winter lacking in abundant rainfall cannot be compensated for by an average one. Unchanged average rainfall does not in any way imply unchanged replenishment.

FIGURE VIII/3

Groundwater recharges during abundant winters, while an average winter barely raises the level.



Median change in the water table from August to January, in cm, by thirds based on precipitation during the winter half-year (October–March). Homokhátság monitoring network, 24 winters.

SOURCE The tertile table in Section III.1; own illustration.

NOTE Lower third (121–209 mm): –7.8 cm, a rise in three out of eight winters. Middle third (212–255 mm): +2.5 cm, in five. Upper third (272–385 mm): +24.0 cm, in seven. The figures relate to the Sand Ridge network and are not national (III.1).

Self-reinforcing processes and irreversibility. Certain changes reinforce themselves. It is an obvious assumption that a dried-out surface absorbs falling water less effectively, thus increasing the proportion of runoff. We were unable to verify this using domestic data sets due to a lack of data, so we did not include it among the statements (III.4). On a global scale, tipping points represent the same phenomenon: systems which, once a threshold is crossed, change state in a self-sustaining manner and, on a human timescale, typically do not revert even if warming ceases.¹⁶⁰ Irreversibility is also evident on the domestic scale, although our knowledge of this is currently based on second-hand reports, without primary verification. In salinising soil, bound sodium remains in place even after the water table has fallen, and the soil becomes compacted and more susceptible to drought (IV.3). It takes decades for confined groundwater levels to recover (III.2). Where the path to recovery is long or non-existent, the ‘we’ll fix it if it goes wrong’ strategy does not work.

Finally, a human factor also comes into play. People regularly underestimate processes that grow exponentially or at an accelerating rate. In a classic series of experiments, a significant proportion of participants estimated only a fraction of the correct value, and this error persisted despite specific explanations and their everyday experience of growth

processes.¹⁶¹ As the experiment was conducted on a small sample, the direction of the effect can be cited, but not its magnitude.

WHAT DOES THIS MEAN FOR PLANNING

Dimensioning should be based on the frequency of days, events and situations exceeding the threshold, not on changes in the average. In any long-term decision, a separate question is where the system's thresholds lie, and whether the damage is reversible if they are exceeded. Where it is not, the value of prevention is disproportionately high (G.5).

VIII.2 Slow erosion and sudden shifts

Crises typically arise from the convergence of two processes occurring at different speeds. The literature refers to these as 'load' and 'triggering event'. The load weakens the system slowly, over years or decades, and does not cause any visible damage for a long time, while the triggering event is rapid, unfolding over days or months. A crisis occurs when the triggering event strikes a system that has been weakened by the load.¹⁶²

The two speeds represent two phases of the same process, but planning requires different tools for each. The following two sections therefore deal with them separately.

Slow erosion: deterioration that is not apparent in any single year

In domestic measurements, such a slow load is reflected in the quarter-century-long drop in groundwater levels at almost all wells east of the Danube and in the decrease in the median number of days with snow cover in the Great Plain from 22 to 6 between 2003–2014 and 2015–2026 (III.1). The same applies to population ageing and the obsolescence of vulnerability data (IV.2).

Three factors conceal this slow erosion. (1) There is no single event to draw attention to it, as falling groundwater levels do not cause a disaster in any given year. (2) The baseline is shifting. If planning always compares the present with the previous few years, every year in this deteriorating trend appears 'normal'. Between 2021 and 2025, the average maize yield fell by 15 per cent compared with the 2006–2020 level (V.2). When measured against a moving average that is constantly adjusted to previous years, this same decline is partially obscured, as the poor years are also included in the baseline. The calculation in V.2 also shows that, by the end of the series, the rolling reference base underestimates the shortfall. (3) Statistical confirmation is delayed. A trend cannot be established from a short series (H.2, III.1); therefore, by the time a slow change

becomes statistically detectable, it has already been underway for a long time.

The latter is a direct application of the two types of error (G.5). If planning responds only to statistically confirmed changes, it will consistently lag behind slow deterioration. Rigor in measurement and caution in planning are therefore two separate issues. Rigor is justified in measurement, while in planning, the absence of proof does not imply the absence of danger.

Sudden shift: when the system changes state abruptly

The triggering events were the 2022 drought, the Danube floods of September 2024 and the summer of 2026 (II.2, II.4, V.2). Sudden changes appear in three forms in domestic measurements. The distinction between these three forms is based on our own classification.

The first is the sharp threshold of engineered systems. Engineering systems are designed to specific limit values; examples include cooling water temperature specifications, the crest height of a dam, or the transmission capacity of a network component. Below this threshold, the system operates at full capacity; above it, a significant portion of its performance is lost all at once. The Danube's minimum summer flow rate at Paks has been fluctuating for decades. The 2026 figure was the lowest in the 37-year series; however, no trend can be discerned from a single year (VII.5). When the water flow and water temperature reached the limits set by the cooling water regulations, the situation—which had been fluctuating for a long time—turned into an operational incident within a single week. On 29 July, according to public statements, the power station shut down an entire unit for the first time in its history due to low flows (IV.4).

The second is an extreme event that far surpassed the previous record. In a warming climate, records are being broken by ever-greater margins (VIII.1, VI.4).¹⁵⁸ The national total rainfall for the summer of 2026 was 74.1 mm, 27.2 mm below the previous record set in 1952 (II.2). In Szeged, the longest dry spell during the growing season lasted 53 days, 12 days longer than the previous local record. The national picture is more moderate. Averaged across the ten stations that have been recording data since 1901, the period lasted 30.2 days, more than two standard deviations above the 1991–2020 average, but only 1.2 days longer than the 1992 peak (II.2). Whether we are seeing a spike or a turning point cannot be determined on the basis of a single year; however, section VIII.8 specifies what kind of observation would be required to make such a determination.

The third is a change of state: after a long, stable phase, the system settles at a new level or in a new direction. The level of confined groundwater stagnated for twenty years, but since 2019 it has been falling suddenly and across a wide area. Whether this is caused by climatic effects or increased extraction remains undecided in the absence of extraction data (III.2). On a global scale, the tipping elements represent the same thing (VIII.1). The most significant factor from a domestic perspective – the weakening of the Atlantic Overturning Circulation – is discussed in section VII.6. The timing of its occurrence is highly uncertain.

The sudden turnaround comes as a surprise because expectations are shaped by the past. Planners and operators regard the most recent record as the worst-case scenario and size their reserves accordingly. Prior to the 2026 dry spell, the average for the longest dry spell between 2016 and 2025 was below normal; recent experience therefore pointed in precisely the opposite direction (II.2). Such a turnaround is rarely without precedent, as it is preceded by a gradual build-up of stress, and this is the point at which slow erosion becomes visible.

WHAT DOES THIS MEAN FOR PLANNING

Slow-changing variables must be measured against a fixed reference point, not a moving average. It must be stated in advance which threshold, once crossed, triggers a decision: in this way, the decision does not depend on when the deterioration can be statistically verified. In the event of a sudden turnaround, two questions must be asked: where are the system's critical limits, and what happens if the next extreme event is significantly greater than the most recent record? The warning signs in Section VIII.7 relate to such slow-changing variables and thresholds.

VIII.3 Interlinked risks: concurrent events, knock-on effects, mutually reinforcing crises

Traditional risk analysis deals with one hazard at a time: drought separately, heatwaves separately, and floods separately. One of the fundamental tenets of the literature on complex climate events is that this method systematically underestimates risk. If hazards are interrelated, the combined risk may be much greater than the independent sum of the individual risks.¹⁶³ For this reason, the rule applied throughout this document is that the probability of a combined occurrence cannot be estimated by assuming the hazards are independent – that is, by multiplying the individual probabilities – because the value obtained in this way is an underestimate (VII.7, VIII.6).

The typology of compound events in the specialist literature distinguishes four types.¹⁶⁴ The analysis classified the domestic examples.

Type	Meaning	Domestic example
Conditional	the extent of the damage is determined by the system's prior state	A winter with 227 mm of rainfall raised the groundwater level by nearly seventy centimetres following the previous year's record rainfall, because the soil was already wet; conversely, a late, snowy winter with 385 mm of rainfall did not result in a measurable rise, but in that case the timing of the thaw was the decisive factor (III.1)
multivariate	multiple hazards affect the same system simultaneously	In the summer of 2026, heat, drought and low flows in the Danube simultaneously affected the electricity supply and agriculture (II.2, IV.4)
temporally cumulative	consecutive events; the system does not recover between two events	two consecutive years of drought, with no winter recharge (VIII.6, Band C)
spatially complex	simultaneous events in multiple locations affecting the same system	a simultaneous drought in upstream countries and a domestic drought, as 96 per cent of the water supply comes from abroad (VII.7); in September 2024, flooding on the Danube and low flows on the Tisza within a single month, placing a strain on the same water-management emergency response capacity (II.4)

One of the findings of this typology, which is particularly important for planning, is that a compound event can cause serious damage even if none of its components is extreme in a statistical sense.¹⁶⁴ Two summers in a row that are slightly worse than average, or a moderate drought combined with low river levels, would not, when considered in isolation, be classified as a high risk.

A compound event is the convergence of hazards, while a spillover risk is the spread of an impact from one system to another.¹⁶⁵ The analytical framework for cross-border climate impacts identifies four steps: the initial impact somewhere in the world; its propagation via trade, financial, infrastructural or social channels; the risk to the receiving country; and, finally, the feedback from response measures.¹⁶⁶ Two well-documented examples from the literature are:

- Following the 2010 heatwave and drought in Russia, the country banned grain exports, which also drove up food prices in the Middle East and North Africa. The authors cite this price rise as one of the contributing factors to the 2011 Arab Spring.¹⁶⁶ This chain of events must be inter-

puted with caution. According to the environmental security literature, climate may be one of the contributing factors to the risk of armed conflict, but it is not the sole cause. Participants in an expert survey agree that climate has influenced armed conflicts, but they consider its historical role to be less significant than that of other factors, and the mechanism of its impact is uncertain. Low socio-economic development and weak state capacity carry significantly greater weight. Climate disasters primarily increase the risk of conflict in places where political exclusion and low levels of development are also present.¹⁶⁷ The lesson from this example therefore relates to the channel of spillover, that is, the way in which food price shocks spread across borders and have an impact where society is already vulnerable.

- During the 2018 European heatwave, low flows in the Rhine simultaneously affected industrial transport, energy production and agriculture.¹⁶⁶

Section VII.7 lists the domestic channels: water arriving from across the border, food prices, fertiliser and energy, the financial system, and population movement.

Ripple effects are rare but have a significant impact. In 120,000 simulations of a synthetic, interconnected electricity and water supply system modelled on a major American city, each triggered by the failure of a single power line, the vast majority of disruptions remained localised, while approximately 4 per cent (3.69 per cent) developed into widespread, system-spanning chain reactions.¹⁶⁸ The lesson for planning is that preparations must be made for rare events, because managing frequent, localised disruptions does not prove that the system can withstand a chain reaction. We draw this conclusion from the results of a synthetic model, as there are no suitable domestic studies.

Finally, crises can also become intertwined. The literature refers to a ‘polycrisis’ as a situation in which crises in multiple global systems are causally intertwined and, together, typically cause greater damage than they would individually.¹⁶² As the term is also becoming a buzzword, we shall stick to the scientific definition here. According to this, crises intertwine in three ways:

- 1 Shared burden.** The same burden weakens several systems simultaneously. A domestic example: summer water shortages place a simultaneous strain on agriculture, energy production and the drinking water supply.

- 2 Domino effect.** A crisis in one system triggers a crisis in another. Domestic example: low flows can lead to reduced output at power stations, which in turn can lead to electricity imports and price rises.
- 3 Inter-system feedback.** Crises reinforce one another. A domestic example: drought increases water abstraction for irrigation and drinking water; this excess abstraction further depletes groundwater reserves; and the depleted reserves make the next drought more severe.

The analysis categorised these three domestic examples. The most significant form of feedback between systems, from a planning perspective, is referred to in the literature as ‘derailment risk’. The intensification of climate impacts causes damage, necessitates crisis management and imposes a budgetary burden. This diverts attention, money and political support away from emissions reduction and adaptation, which slows down the transition and further exacerbates the impacts (Figure VIII/4). The more simultaneous crises there are to manage, the less attention and resources are allocated to prevention. This is how derailment links the channels in Section VII.7 at the decision-making level. The cycle can also work in reverse, as an extreme event can also accelerate action. The sources do not quantify which direction prevails. The risk-taking recommendation in the British actuarial report includes ‘derailment risk’ among its six points.¹⁶⁹ Derailment also jeopardises the achievement of the favourable emission trajectories described in Section VII.2.

FIGURE VIII/4

Derailment risk: climate impacts may undermine the capacity for prevention.



Mechanism diagram; no probability is assigned to the cycle.

SOURCE Own compilation based on Laybourn, Evans and Dyke (2023); Laybourn et al. (2025).

NOTE The cycle can also operate in a reinforcing direction: an extreme event can accelerate action. The sources do not quantify the relative importance of the two directions.

The authors of the polycrisis definition themselves state that the polycrisis threshold is a qualitative category, and that the delineation of system boundaries is a matter of agreement. The framework should therefore be regarded as a conceptual aid, not as a measuring tool.¹⁶²

WHAT DOES THIS MEAN FOR PLANNING

For every risk, one must ask: what else goes wrong at the same time, due to the same cause? Stress tests should be prepared for the combined scenario, not for individual hazards separately. Triggers beyond national borders, such as upstream drought or the international fertiliser market, must be monitored just as closely as domestic ones.

VIII.4 Why this is difficult for conventional thinking and planning

The patterns described in the previous points are well known. The fact that planning nevertheless regularly overlooks them has two dimensions: individual thinking and institutional practice. It is true of both that conventional methods worked well in a stable world. The problem arises when the world is no longer stable, yet the method remains the same – this is the assessment of the analysis.

In individual thinking, four well-documented patterns directly affect climate planning.

- *Normalcy bias*. This is the term used in disaster research to describe the tendency to underestimate the probability or scale of an expected disruption. The initial reaction to a warning is typically disbelief.¹⁷⁰ In planning, this manifests itself in the fact that the plan does not take into account events that have not yet occurred.
- *Underestimation of exponential growth*. We regularly perceive processes that are growing at an accelerating rate as linear (VIII.1).¹⁶¹
- *Planning optimism*. In large international infrastructure samples, the costs of railway projects exceeded the planned figures by an average of 44.7 per cent, those of bridges and tunnels by 33.8 per cent, and those of public roads by 20.4 per cent. The author identifies two causes: self-deceptive optimism and deliberate misrepresentation. The remedies for the two are different: for the former, the solution lies in methodology; for the latter, in accountability.¹⁷¹
- *Psychological distance*. Many people perceive climate risk as distant in terms of time, space and society. In such cases, fear-inducing messages often provoke a reaction of disengagement and do not encourage action.¹⁷² This is why, in this analysis, we discuss outcomes that can still be avoided (G.5).

The scientific literature supports these patterns with evidence of varying strength. The laboratory measurement of optimism bias is controversial; some researchers regard it as a methodological flaw.¹⁷³ Systematic cost overruns in projects, however, have been confirmed in a large sample, and the author of the study himself demonstrates that part of the overrun can be attributed to conflicts of interest.¹⁷¹ Cognitive biases therefore do not in themselves explain planning errors; institutional practice matters at least as much.

In terms of institutional practice, a 2024 British security policy analysis identified four structural flaws in the way governments manage climate risk.¹⁷⁴

- 1 *First-order bias*: attention is focused on direct impacts (floods, heat-waves), but not on knock-on effects (supply chains, budgets, political stability).
- 2 *The assumption of gradualism*: climate change is viewed as a slow, steady process, even though the impacts are non-linear.

- 3 *Separate ministries:* climate risk falls under the remit of the environment ministry, while security risk is handled by another ministry, and no one links the two.
- 4 *Risks treated as having a low probability:* tipping points are deemed unlikely and pushed into the background, even when the estimated probability is by no safety standard considered low.

This is associated with two professional habits. The first is the assumption of constancy: for decades, water management and engineering design have been based on the premise that past statistics apply to the future as well. In 2008, the water management literature established that this assumption is no longer tenable due to climate change.¹⁷⁵ The second is the convenience of the model mean: the mean value of the models appears to be a design value, even though, for four indicators, the entire model range falls below the measured values (H.2).

Finally, there is the term of office. The budget is annual, the cycle is four-year, while slow change takes place over decades. Slow deterioration therefore does not appear as an urgent task in any single planning period. The UK National Risk Register addresses this dilemma openly and, since 2020, has been discussing chronic risks, including climate change, separately from the probabilistic assessment. It also states that chronic risks make acute risks more likely and more severe.¹⁷⁶

a cognitive trap	how it manifests in planning	antidote
normalcy bias	there is no plan for what has not happened yet	reasonable worst-case scenario; pre-written storylines (VIII.5)
exponential underestimation	linear extrapolation	threshold-based indicators; fixed benchmark (VIII.1, VIII.2)
planning optimism	underestimated costs and time	external comparison with similar previous projects
one risk at a time	the combined scenario is omitted	combined stress test (VIII.3)
separate portfolios	no one sees the chain	shared risk profile, designated responsible party (IX.12)
assumption of stability	past statistics form the basis for sizing	the measured trend and the minimum rule (H.2)
convenience of the model mean	the mean as a design value	the bottom of the band as a lower bound (H.2, VII.8)
delay in verification	reacts only to confirmed changes	pre-defined decision thresholds (VIII.7)

The countermeasures in the table were compiled by the analysis based on the cited sources and the previous chapters.

VIII.5 What can be done: from forecasting to preparedness

The essence of the shift in thinking lies in turning a question on its head. Conventional planning asks: what is the most likely future, and how should we prepare for it? The risk-based approach asks: what could happen that would cause serious harm, and what can still be avoided (G.1)? There is no single correct forecast for the second question, but there are best practices. Each of the following is in use somewhere within the public administration, and their application in Hungary is recommended by the analysis.

- 1 **The reasonable worst-case scenario and narrative threads.** The UK National Risk Register formulates, for every risk, the worst-case scenario that remains after excluding highly improbable scenarios, and scales preparedness measures accordingly (G.3).¹⁷⁶ Climate literature recommends ‘storylines’ for the same purpose: physically consistent, concrete descriptions of events, which are more comprehensible to decision-makers than probability distributions.¹⁷⁷ In this analysis, the storyline is Band C (VIII.6). A narrative is useful when it is specific: what happens in which month, on which river, at which power station, and in which county.
- 2 **Stress test and reverse stress test.** A stress test examines whether the system can withstand a given event. A reverse stress test approaches the issue from the opposite direction, seeking to identify what combination of factors would lead to an unacceptable outcome and how likely that is.¹⁷⁸ A report published by the professional body of British actuaries assesses climate risk using this logic, from the perspective of avoiding failure.¹⁷⁸ Chapter VII based its outlook for 2050 on this logic. Translated into public administration practice, a reverse stress test might, for example, be phrased as follows: under what combination of simultaneous events would a county in the Great Plain be unable to provide drinking water and air-conditioned rooms for people aged 75 and over for two weeks? The question is the analysis’s own example.

- 3 **Pre-defined decision points and adaptation pathways.** In situations of deep uncertainty, it is advisable to plan adaptation pathways rather than a rigid plan. The pathway specifies which measure remains sufficient until when, at which threshold the next measure should be adopted, and which decision would preclude future options.¹⁷⁹ In the Dutch Delta Programme, every region goes through the same cycle: stress test, risk dialogue, implementation programme.¹⁷⁹ The twelve warning signs listed in Section VIII.7 could serve as the indicator system for this method. An indicator is only useful if it is pre-defined what happens when it is triggered.
- 4 **Testing assumptions and preliminary failure analysis.** The methodology of intelligence analysis provides several tools for testing one's own assumptions. One is the testing of key assumptions: for every plan, it must be noted what it is based on and which assumption, if it were to fail, would cause the plan to fail. Another is ex ante failure analysis: the team assumes that the plan has failed five years down the line and works backwards to identify the cause.¹⁸⁰ There is little independent evidence regarding the effectiveness of these tools, so they should be used with moderate expectations.¹⁸⁰ They are inexpensive and, at the very least, make blind spots visible.
- 5 **Resilience.** In ecology, the resilience of a system means that it is capable of absorbing change and disturbances while maintaining its functioning. This is a different property from stability, which refers to a rapid return to a state of equilibrium.¹⁸¹ Engineering literature distinguishes between four meanings: recovery, resistance, flexible adaptation to unexpected situations, and sustained adaptability. An important observation is that if a system is made increasingly capable in one direction, it may become more fragile in another direction.¹⁸¹

For public administration, this gives rise to four practical characteristics. The list was compiled by the analysis based on the referenced literature.

- *Reserve*: the capacity that remains unused in normal times but is available in the event of a disruption. In a system optimised for cost-effectiveness, this is precisely what disappears first.
- *Diversity*: if a need is met by several sources that can be disrupted in different ways, a single disruption will not paralyse the whole system.
- *Modularity*: the parts of the system can be isolated from one another, so that a disruption does not spread throughout the whole system (VIII.3).

- *Knowledge of interconnections*: it is necessary to know which system depends on which. We cannot isolate what we do not know.

6 Preparedness extending to society as a whole. According to the European Union's preparedness report, the Union requires a comprehensive risk assessment covering all hazards and threats. The report recommends that preparedness be integrated into all policy decisions, and that households be self-sufficient for at least 72 hours.¹⁸² The report discusses climate, epidemiological and military threats as inter-linked risks. The lesson for national planning is that climate preparedness and general civil preparedness are based on the same capabilities: reserves, functioning local supply, reliable information and practice.

This shift in thinking can be summarised in five shifts. The table was compiled as part of the analysis.

Conventional thinking	The necessary mindset
plans for the average	planning for thresholds and extremes (VIII.1)
examines one hazard at a time	examines the combined event and the chain of events (VIII.3)
predicts the most likely future	starts from the outcome to be avoided and prepares for it (VIII.5)
a rigid plan, once adopted	a course that can be altered at pre-determined decision points (VIII.5, VIII.7)
plans by sector	manages linkages and the common reserve (VIII.3, IX.12)

This approach is not a call for despair. Risk-based thinking demonstrates precisely that some outcomes can still be avoided, and which decisions matter most (G.5).

VIII.6 Three possible scenarios for the coming decade

This chapter applies the above way of thinking to three possible trajectories for the coming decade. These three trajectories are hereafter referred to as 'bands'. The bands are not new scenarios, but rather organise the measurements from previous chapters and the decade-long forecast into three states that can be distinguished from one another through observation, which Section VIII.7 translates into warning signs.

The bands are based on three concepts introduced earlier. Winter half-year recharge refers to precipitation between October and March, which replenishes the groundwater supply. According to Section III.1, the threshold for wells in the Sand Ridge region is approximately 185 mm;

below this threshold, the groundwater level does not rise in net terms during winter. In other regions, the threshold is different. The average winter (239 mm there) exceeds this threshold, but it barely raises the groundwater level, as reserves are replenished during winters that fall within the upper third in terms of precipitation. The working model for the decadal prediction consists of ten runs of the HadGEM3 model for the period 2025–2034, measured against the model's own 1991–2020 reference period, with the central value being the average of the ten runs (II.1). According to the minimum rule (H.2), the lower limit for planning is the value already observed: what has been recorded once cannot be treated as impossible in planning, even if it falls below the range of the models.

- **Band A – favourable.** Over the decade, abundant winters will occur more frequently than at present, while the summer heat load will remain in the lower half of the central value. The depletion of reserves will cease, and the damage will remain manageable.
- **Band B – planning basis.** The central projection of the working model is realised: the annual mean temperature exceeds the model's own 1991–2020 reference by approximately 1.7 °C, and the summer mean by 1.9 °C, while the number of extremely hot days increases. Winter precipitation remains above the threshold on average, but abundant winters will not be any more frequent than at present. Replenishment is therefore unlikely – as has been the case over the past quarter of a century – to make up for summer losses, and the reserve will continue to be depleted slowly. **This band carries the highest probability weight**, and due to the minimum rule, planning must start from this point.
- **Band C – compound stress.** In two or more consecutive years, winter half-year precipitation falls below the threshold, and replenishment fails to occur. This is compounded by a build-up of summer heat – several consecutive heatwaves – with low-flow curtailment of output on the energy side. In these same years, spring frost damage may also occur. This is not causally linked to the dry winters, but is an independent risk superimposed on the others. This is not the most likely scenario, but it is a reasonably plausible one, and preparations must therefore be scaled accordingly. According to the types outlined in Section VIII.3, this is both a temporally cumulative and a multivariate event: the system does not recover between two bad years, and the majority of the hazards arise simultaneously from a common cause.

We do not assign numerical probabilities to the bands, as the joint probability of the individual elements cannot be reliably estimated, and the assumption of independence would underestimate the joint occurrence (VIII.3).

VIII.7 Twelve warning signs: which scenario is the decade (2027–2031) heading towards?

These signs are based on observation; rather than making predictions, they indicate which trajectory we are on before the consequence materialises. Using the terminology from Section VIII.2, the signs are slow-changing variables and thresholds. For each one, it must be established in advance what decision its crossing will trigger; otherwise, the sign remains merely an observation (VIII.5). The signals for the early years may be distorted by an exceptional event. According to an assessment by the US Climate Prediction Center on 8 October, the El Niño strengthening in the autumn of 2026 has an 83 per cent probability of being stronger than any El Niño recorded since 1950 between October and December.²²⁴ This will cause a one-off spike in global temperatures in 2026–2027, which should not be treated as a sustained acceleration (VI.1). The impact on Hungary is more uncertain: the Carpathian Basin lies on the boundary between the northern and southern European impact patterns,^{225,226,227} therefore, in our view, it is not possible to plan for an average El Niño impact here. The first-year values for winter precipitation in 2027 (indicator 1), tropical nights (indicator 5) and post-budburst frost (indicator 7) must therefore be interpreted in the context of the El Niño year, and the trajectory should not be changed on the basis of a single year.

#	Indicator	Data provider
1	Winter half-yearly precipitation compared with the 185 mm recharge threshold measured at wells in the Sand Ridge region – three consecutive years; in other regions, the threshold must be measured separately. Attention should also be paid to the frequency of abundant winters falling within the top third of the local distribution (III.1): this is what distinguishes Band A from Band B.	HungaroMet (precipitation grid); Water Management Service (well networks)
2	The trend in the August minimum levels of the national network of reference wells, and whether abundant winters raise the level back to previous peaks.	Water Management Service

#	Indicator	Data provider
3	An explanation for the break in the trend in deeper confined groundwater levels in 2019 – provided that abstraction data is available for the period.	Water Authority (extraction data)
4	Decadal trend in the number of days with a daily mean temperature of ≥ 25 °C.	HungaroMet
5	Number of tropical nights in major cities.	HungaroMet
6	The relationship between excess mortality and heat stress: is the adaptation effect waning or is it persistent (IV.1)?	NNGYK; KSH
7	The frequency of frost damage after bud burst over the next five years – confirmation or refutation of the observations from the 2021–2025 period.	HungaroMet (agrometeorology); AKI (damage mitigation)
8	The number of days with water levels below the low-flow threshold, broken down by the summer window and for the whole year. On the Körös and Maros rivers in 2026, the average summer discharge was at the lowest level in the series dating back to 2000; at Makó, the water level was below the lowest recorded value on five days (III. 1).	Water Management Service
9	Verification of the decadal prediction: whether the actual data for 2026–2030 fall within the forecast range.	HungaroMet (actual data); forecast provider
10	Are the national vulnerability data layers being updated (IV.2) – this is an institutional, not a climatic, indicator, but it is the factor that most determines the quality of the risk profile.	HungaroMet (NATÉR)
11	Is a pentad-scale, root-zone soil moisture series being developed , on which rapidly developing drought can be measured at all? This is also an institutional indicator: until such a series exists, we have no domestic data on the main cause of crop damage (H.4).	No designated data custodian
12	The longest dry spell during the growing season (April–September), averaged across the ten homogenised stations that have been recording data since 1901: was the 2026 record (30.2 days) an outlier or a turning point? Decision window: 2027–2031 (II.2, VIII.8).	HungaroMet

VIII.8 What would refute the conclusions

The following factors could refute or significantly weaken the above conclusions. The direction of the final point is the opposite, as its fulfilment would provide a basis for moderating the weighting of the risk.

- If, over the next five years, groundwater levels at wells east of the Danube begin to rise persistently even with average winters – the two main findings of Chapter III will be weakened. One is that the drawdown there is unidirectional; the other is that recharge is concentrated in abundant winters.
- If the observed trend in the vapour pressure deficit is broken, or if it transpires that the measurement grid contains a systematic error, the key finding of section II.2 – namely that the strongest observed sign of drying is an increase in the vapour pressure deficit – will be refuted.
- If a new generation of projections (the downscaled products of the new model suite) reproduces the observed evaporation and temperature trends, the minimum rule is weakened and the midpoint of the model range regains its role in planning.
- If, in at least two years between 2027 and 2031, the longest dry spell during the growing season at the ten stations reaches 28 days on average, the 2026 record cannot be regarded as an outlier. Assuming the distribution remains unchanged, the probability of this is approximately 0.7 per cent (there were three such years between 1901 and 2025: 1961, 1992 and 2007). In this case, the assertion in section II.2 that the duration of the dry spell does not increase must be re-examined in relation to the growing season, and it must also be investigated whether the minimum rule applies to the duration of the dry spell. A single such year is not decisive, as under an unchanged distribution it occurs with a probability of approximately 12 per cent over a five-year period.
- If the excess mortality data follow the 2026 pattern over several years amidst an increasing heat burden, the adaptation hypothesis in Section IV.1 will be confirmed, and the weighting of the health risk should be adjusted downwards. According to the hypothesis, heat alerts, the spread of air conditioning and public awareness have reduced the mortality impact of heat.

IX

Planning conclusions and actions by sector

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This chapter translates the results of the analysis into the various areas of public administration, i.e. it explains what they mean for each sector and what actions follow from them. The actions are our own recommendations, based on the measurement results from the previous chapters, while the underlying findings can be found in the section indicated in brackets. This chapter does not provide any cost estimates or timetables, nor does it make any recommendations regarding investment. The actions to be taken fall into four categories:

- data: filling in missing measurements or updating obsolete data layers;
- regulation: amendment of a dimensioning standard, funding condition or procedural rules;
- operation: supplementing the operational procedures or testing conditions of an existing system;
- preparation for investment: establishing the design basis prior to a subsequent decision.

The table in Section **IX.13** summarises the most important actions and their nature by field. For several of these actions, established practices in other European countries serve as models; these are identified in the

notes. The model demonstrates that the step itself is feasible, but does not prove its impact in the domestic context.

Overview of actions by decision-making timeframe

The table below organises the 66 key actions in this chapter according to the timing of the decision. The order of the actions is determined by how long the decision is binding and when it can be taken. The classification and the degree of confidence in the evidence are the authors' judgement and do not follow directly from the data.

- **Now, without regret:** a low-cost or cost-free step that is appropriate across all three risk bands of the coming decade and is often a prerequisite for other decisions: data, measurement, regulations, maintaining existing capacity.
- **Decision window:** the decision has a fixed timeframe (budget, EU cycle, plan review, legislative preparation). Once the window closes, there is no new opportunity until the next cycle. Where the window is currently open, this is indicated separately.
- **Long-term decision:** an investment or installation that will remain operational beyond 2050. The decision is being made now, but its consequences will last for decades; therefore, the planning levels set out in Section IX.1 apply to it.
- **Decision contingent on a signal:** the decision does not need to be made now, but it must be established now what signal or event will trigger it (VIII.7).

The confidence in the evidence underpinning the actions is indicated on a three-point scale; the rating is assigned based on the nature of the evidence base: how many independent measurement lines support it, how long the series is, and whether the data is preliminary. The reliability refers to the finding on which the action is based, not to the correctness of the action itself. Where one part of the finding is strong and the other weak, the rating specifies both, for example, 'medium for the decline, low for the cause'. The ratings 'high for data gap' and 'high for obsolescence' indicate that the absence of data or the obsolescence of the data is well-documented.

- **High:** a finding based on measured data, with multiple independent lines of measurement converging on the same result; the source data is publicly available, the calculation is reproducible, and it has been verified by an independent re-calculation.

- **Medium:** a measured indicator based on a short period, a single event, or partly on preliminary data, a model or an expert assessment. The direction is well-founded, but the frequency or magnitude is not.
- **Low:** the phenomenon is measurable, but its cause or magnitude cannot be identified from domestic data because the necessary data or time series are missing.
- **Institutional:** the action to be taken is not based on measurement findings, but on legislation, institutional shortcomings or foreign practice; measurement reliability is not applicable here.

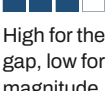
The first line of the ‘Where to find it’ column refers to the section in the analysis chapter where the finding underpinning the action item is presented, together with the methodology and uncertainty. The second line refers to the section in Chapter IX where the full justification for the action to be taken can be found. Where the first line is missing, the action to be taken is based on an external source, legislation or institutional decision specified in Chapter IX.

Action	Sector	Decision window, justification	Evidence	Where to find it
Now, without regret (35)				
For the four most important indicators, the measured value, rather than the model, is the starting point.	Common rules for all disciplines	A basic rule, applicable immediately at no cost; the framework for all other design decisions.	 High for temperature and days at 30 °C, high for the measured increase in vapour pressure deficit, and moderate for model underperformance and spring frost	H.2 IX.1, 1.
Preparations must be scaled to account for the unfavourable but realistic scenario.	Common rules for all disciplines	Design principle; it is decisive where a long-lived facility is being built.	 Medium	G.5, VIII.6 IX.1, 2.
The phasing out of cold-side provision is premature.	Common rules for all disciplines	This concerns the maintenance of existing capacity. In our view, scaling it back would be premature in the coming decade.	 Low	II.4 IX.1, 4.
Water abstraction must be made measurable even where it is not currently measured.	Water management	The least expensive measure and a prerequisite for all water management decisions.	 High for the data gap	III.1, III.2 IX.2, 1
The sequence of interventions must be determined on a regional basis.	Water management	Planning data preparation; this should be completed in time for the VGT4 consultation (Dec. 2026–June 2027).	 Medium	III.1 IX.2, 3.

Evidence:  high ·  medium ·  low ·  institutional

Action	Sector	Decision window, justification	Evidence	Where to find it
Aquifer water extraction must be measured, and the protection of drinking water sources must be adapted accordingly.	Water management	Measuring abstraction is inexpensive and urgent. Protecting drinking-water sources is a long-term decision, to be taken following the measurement.	 Medium for the decline, low for its cause	III.2, III.5 IX.2, 5.
The reduction in frost protection capacity is premature.	Agriculture and rural development	This concerns the maintenance of existing frost protection capacity. The 2021–2025 signal is a five-year observation, not a trend.	 Medium	II.3 IX.3, 3.
It is necessary to assess the extent of damage that the damage mitigation scheme is capable of covering.	Agriculture and rural development	Survey, low-cost; results form part of the input for budget planning.	 Medium	IV.3 IX.3, 5.
Droughts developing over a period of a few weeks must be monitored.	Agriculture and rural development	Filling gaps in measurements.	 Low	H.4, VIII.7 IX.3, 6.
The forestry climate zone map needs to be updated with data from 2011 onwards.	Forestry	Data update, a prerequisite for planting decisions.	 High for obsolescence	II.6 IX.4, 2.
Power reductions due to low flows must be incorporated into the design studies of the electricity system.	Energy	Operational decision; no investment required.	 Medium	IV.4, G.5 IX.5, 1.
The assumptions underlying water management authorisation and energy planning must be aligned.	Energy	Alignment of assumptions, at no cost.	 Institutional	IV.4 IX.5, 2.
Peak demand planning should take into account the simultaneous occurrence of heatwaves and low flows.	Energy	Planning methodology rule.	 Medium	VII.7, VIII.3 IX.5, 4.
Preparations for heatwaves should focus on four target groups: the elderly, people with chronic conditions and those who are bedridden, pregnant women and young children, and outdoor workers.	Health and social care	Identification of target groups for care planning, at no cost.	 Medium for the elderly, low for the other groups	IV.1, IV.2 IX.6, 1.
The heatwave warning system must not be dismantled.	Health and social care	Decision to retain; dismantling it would have immediate adverse consequences.	 Low	IV.1 IX.6, 2.
The link between heat and mortality must be continuously monitored.	Health and social care	Continuation of data series.	 High for the data gap	IV.1 IX.6, 3.
The heat risk map needs to be updated.	Health and social care	Data update, quick and inexpensive.	 High for obsolescence	IV.2 IX.6, 4.
Alerts and care planning should be based on the daily average temperature and tropical nights.	Health and social care	Adjustment of alert thresholds, at no cost.	 Medium	II.1 IX.6, 5.

Evidence:  high ·  medium ·  low ·  institutional

Action	Sector	Decision window, justification	Evidence	Where to find it
A climate review of building and infrastructure design regulations must be ordered, with a deadline and a designated person responsible, for both extremes.	Buildings, settlement structure and infrastructure	The directive may be issued immediately; the review itself runs over several cycles.	 Institutional	IX.7, 7.
Municipal heatwave plans must first be updated in the counties most severely affected.	Local authorities, urban planning and disaster management	Plan update; the ranking is based on the combined effect of heat stress and excess mortality due to heatwaves.	 Medium	IV.2 IX.8, 1.
Disaster preparedness exercises should be based on the concept of a 'year of combined stress'.	Local authorities, urban planning and disaster management	Amendment of the exercise scenario.	 Medium	VIII.6, VII.7, II.4 IX.8, 4.
The municipal adaptation plan should be based on a local stress test.	Local authorities, urban planning and disaster management	Local assessment; input to the municipal planning cycle.	 Institutional	IX.8, 6.
An official national economic loss account must be drawn up.	Finance, budgeting and EU funds	Data and record-keeping tasks, the basis for all financial decisions.	 High for the data gap, low for the magnitude	V.1 IX.9, 1.
International damage figures may only be used in conjunction with a domestic basis or their source.	Finance, budgeting and EU funds	Disclosure rule, no cost.	 High for the data gap	V.1 IX.9, 3.
Financial stress tests should also be extended to cover physical climate risks.	Finance, budgeting and EU funds	Methodological expansion, from the next round of stress tests.	 Institutional	VII.7 IX.9, 4.
Concurrent risks must not be treated as independent of one another.	Finance, budgeting and EU funds	Methodological rule.	 Medium	VIII.3 IX.9, 5.
In addition to the damage assessment, a damage financing strategy is also required, which sets out in advance who will pay for major damage and from what sources.	Finance, budgeting and EU funds	Financing must be decided before major damage occurs; afterwards, it is too late.	 Medium	V.2 IX.9, 6.
A mandatory, standardised insurance scheme with a disaster damage surcharge, backed by state reinsurance, should be examined.	Finance, budgeting and EU funds	Review; the introduction of the system requires a legislative decision.	 Institutional	IX.9, 7.
The exposure and vulnerability data layers must be updated.	Statistics, data management and knowledge base	Data update.	 High for obsolescence	IV.2 IX.10, 1.
A public, specified list of climate thresholds must be adopted; in other words, it must be established which climate thresholds the public administration wishes to avoid exceeding.	Statistics, data management and knowledge base	Policy decision, at no cost.	 Institutional	Annex A IX.10, 3.
The data managers for the warning signs must be designated.	Statistics, data management and knowledge base	Designation, at no cost.	 High for the data gap	VIII.7 IX.10, 4.

Evidence:  high ·  medium ·  low ·  institutional

Action	Sector	Decision window, justification	Evidence	Where to find it
Measurements of atmospheric humidity need to be expanded in terms of both space and time.	Meteorological measurements and climate modelling	Filling gaps in measurements.	Medium	II.2 IX.11, 1.
A national measurement network is required for soil moisture in the root zone, with a designated data manager.	Meteorological measurements and climate modelling	Filling gaps in measurements.	High for the data gap	II.2 IX.11, 2.
The vapour pressure deficit in impact assessments must be calculated from the regional models' own air humidity data.	Meteorological measurements and climate modelling	Modification of the calculation procedure.	Medium	II.2 IX.11, 3.
The two domestic projection sets must be regularly compared with measurements in a joint, public test.	Meteorological measurements and climate modelling	Regular comparison, data processing.	High	H.2 IX.11, 4.
Decision window now open (7)				
New and substantially refurbished buildings must meet mandatory summer overheating requirements.	Buildings, settlement structure and infrastructure	The deadline for transposing the Energy Performance of Buildings Directive (2024/1275) expired on 29 May 2026; the Commission sent a letter of formal notice on 15 July 2026; transposition is still ongoing, so a decision can be taken now. The building will stand for decades.	Institutional	IX.7, 1.
Budgetary reserves should be planned to cater for rare years of significant losses.	Finance, budgeting and EU funds	The 2027 budget is expected to be submitted in October 2026.	Medium	V.2 IX.9, 2.
Budgetary provisions for adaptation must be identified.	Finance, budgeting and EU funds	The 2027 budget (to be submitted in October 2026).	Institutional	IX.9, 10.
The adaptation strategy must be accompanied by a five-year implementation programme, with a budget and designated responsible parties for each action.	Adaptation planning and governance	Climate Act (amendment to Act XLIV of 2020 or a new Act), parliamentary decision expected in November–December 2026; there is no public timetable for the review of the National Climate Change Strategy.	Institutional	IX.12, 1.
A national climate risk report should be produced every five years, and the implementation programme should be aligned with this.	Adaptation planning and governance	Climate Act, parliamentary decision expected in Nov–Dec 2026.	Institutional	IX.12, 2.
A uniform temperature rise level for planning purposes must be established, to which all sectoral plans and standards refer.	Adaptation planning and governance	Climate Act or its implementing regulations; parliamentary decision expected in November–December 2026.	Institutional	IX.12, 3.
Climate risk must be assessed within a national risk framework that encompasses other hazards, with a designated coordinator.	Adaptation planning and governance	Climate Act (November–December 2026) and the national risk assessment regulation.	Institutional	VIII.4, VIII.5 IX.12, 5.
Long-term decision (10)				

Evidence: high · medium · low · institutional

Action	Sector	Decision window, justification	Evidence	Where to find it
Facilities that will remain in operation beyond 2050 must be designed for at least 2 °C of global warming, with a 2.5 °C stress test.	Common rules for all disciplines	The facility will remain in operation beyond 2050. The statutory establishment of the design standard is linked to the Climate Act (IX.12, 3.).	 Medium	VII.1, VII.2 IX.1, 3.
When dimensioning reservoirs and irrigation systems, the summer of 2026 is the reference dry period.	Water management	Reservoirs and irrigation systems are built to last for decades.	 Medium, low for the turning point	II.2 IX.2, 4.
The statutory hierarchy of water restrictions must also be incorporated into capacity and investment planning.	Water management	Plans must be aligned with the order of priority for restrictions applicable throughout the lifetime of the investments.	 Institutional	V.4 IX.2, 6.
Plans for the Danube up to 2050 must take into account higher flows in winter and more uncertain flows in summer.	Water management	Cooling water, navigation, drinking water supply: systems operational until 2050.	 Medium	VII.5 IX.2, 8.
When selecting crop varieties and cultivation methods, heat tolerance and frost tolerance must be considered together.	Agriculture and rural development	For plantations, a decade-scale decision; for arable crops, this can be changed annually.	 Medium	IV.3 IX.3, 4.
When planting forests and selecting tree species, allow for a drier climate zone.	Forestry	The forest will remain in place for decades.	 Medium	II.6 IX.4, 1.
For new or expanding capacities dependent on cooling water, the summer water flow in 2026 should be used as a stress test.	Energy	New or expanding cooling water-dependent capacity over decades.	 Medium	VII.5 IX.5, 3.
As a priority, buildings housing people aged 75 and over must be made heat-resistant, and air-conditioned communal spaces must be designated in towns and villages.	Buildings, settlement structure and infrastructure	The refurbishment of these facilities is a long-term process, whereas the designation of air-conditioned communal spaces can be done immediately.	 Medium	IV.2 IX.7, 3.
In settlements within small catchment areas at risk of flash floods, rainwater drainage must be adapted to the measured changes.	Local authorities, urban planning and disaster management	A rainwater drainage network is built to last for decades.	 Medium	III.5, II.4 IX.8, 2.
Planning for municipal water supply should take into account the climate sensitivity of drinking water sources.	Local authorities, urban planning and disaster management	Water supply system and water resources have a long service life.	 Medium	III.5 IX.8, 3.
Subsequent decision window (10)				
Water from the winter half-year must be retained in the landscape.	Water management	VGT4 – public consultation Dec. 2026–June 2027, adoption by 22 Dec. 2027; successor to the CAP (national and regional partnership plan) from 2028, provided the legislation is finalised in time. The works will have an impact for decades.	 High for the decline, medium for the effect of retention	III.1, IV.3 IX.2, 2.

Evidence:  high ·  medium ·  low ·  institutional

Action	Sector	Decision window, justification	Evidence	Where to find it
Different flood preparedness measures are required on the Danube and the Tisza.	Water management	Cycle 3 of the Flood Risk Management Plan, review by 22 December 2027 (the Danube Basin Plan by June 2028); the flood defences have a long service life.	Medium for the measured deviation, low for its cause	III.3, II.4 IX.2, 7.
The vapour pressure deficit (the air's vapour-holding capacity) should be included among the indicators for agricultural planning and eligibility criteria for support.	Agriculture and rural development	The national plan for the post-2028 CAP framework (the chapter on the national and regional partnership plan) is due in 2027; the rules governing the start and the transition are still open.	Medium	II.2 IX.3, 1.
Shading, night-time ventilation and passive cooling should also be eligible for support under the renovation grant scheme for existing buildings.	Buildings, settlement structure and infrastructure	The next call for proposals under renovation support programmes; EU funding from 2028 (an agreement on the 2028–2034 multiannual financial framework is planned for the end of 2026, but this may be delayed).	Low for the domestic magnitude	IX.7, 2.
Climate data for building and structural design must be aligned with measured values.	Buildings, settlement structure and infrastructure	Second-generation Eurocodes – national implementation by 30 September 2027; withdrawal of the first generation by 30 March 2028.	Institutional	IX.7, 4.
In urban planning, the proportion of paved surfaces must be reduced, while green spaces and water bodies must be increased.	Buildings, settlement structure and infrastructure	Review of town planning instruments; development is planned for decades.	Medium	IV.2 IX.7, 5.
Climate risk assessments should be mandatory for facilities built using public funds or EU funding that are intended to remain in operation for more than ten years.	Buildings, settlement structure and infrastructure	Programming of EU funds for 2028–2034 (partnership plans in 2027).	Institutional	IX.7, 6.
Preparations must be made for the national adaptation plan to become a condition for receiving EU adaptation funding.	Finance, budgeting and EU funds	The proposal for a regulation on the EU Climate Resilience Framework was, at the time of closing this text, expected on 20 October 2026; the national plan as a funding condition is, for the time being, only an anticipated requirement.	Institutional	IX.9, 9.
Decadal climate predictions must be incorporated into 5–10-year planning cycles.	Statistics, data management and knowledge base	The 5–10-year sectoral planning cycles.	Medium	H.3 IX.10, 2.
The order of priorities must be established according to public, pre-defined criteria.	Adaptation planning and governance	Drawing up the first implementation programme.	Institutional	IX.12, 4.

Decision contingent on a signal (4)

Evidence: high · medium · low · institutional

Action	Sector	Decision window, justification	Evidence	Where to find it
The expansion of irrigation is conditional on the water balance and water quality.	Agriculture and rural development	A decision on expansion may be taken following the measurement of water abstraction (IX.2, 1.) and the water balance.	■ ■ ■ □ □ Medium	IV.3 IX.3, 2.
The twelve warning signs must be assessed annually.	Local authorities, urban planning and disaster management	The warning system itself: the assessment must be organised now; decisions are triggered by the warning signs.	□ □ □ □ □ □ □ □ Institutional	VIII.6, VIII.7 IX.8, 5.
Compensation and force majeure support should be conditional upon reinforced reconstruction.	Finance, budgeting and EU funds	The rule must be laid down before the year in which major damage occurs; it may be applied in the following year in which damage occurs.	□ □ □ □ □ □ □ □ Institutional	IX.9, 8.
Official national climate products must be updated to the new model generation.	Statistics, data management and knowledge base	This is due when the downscaled products of the new model generation become available.	■ ■ ■ □ □ Medium	VII.8, VII.4 IX.10, 5.

Evidence: ■ ■ ■ ■ □ high · ■ ■ ■ □ □ medium · ■ □ □ □ low · □ □ □ □ □ □ □ □ institutional

Source: actions from Chapter IX. Status of external decision-making windows as at 14 October 2026: the Government's autumn 2026 legislative programme; the planned submission of the 2027 budget (Ministry of Finance, press release); the European Commission's infringement package of 15 July 2026 (Directive (EU) 2024/1275); the VGT4 timetable of the National Water Authority; Article 14 of Directive 2007/60/EC; the JRC timetable for the second-generation Eurocodes; the Commission and Council communications on the post-2027 CAP framework and the 2028–2034 multiannual financial framework; the European Parliament's Research Service briefing of September 2026 on the EU climate resilience framework. EU timetables are subject to change.

IX.1 Common rules for all sectors

We distinguish between three levels of planning.

- The planning basis is the most likely scenario from which planning starts: for the coming decade, Band B in Section VIII.6, which implies global warming of 2 °C by 2050.
- The design scenario is the unfavourable but realistic situation that the facility and the supply system must be able to withstand: Band C in Section VIII.6.
- The stress test examines what happens beyond this, for example in the event of 2.5 °C of global warming. The measured values for the summer of 2026 serve a dual purpose: as a reference event in the dry-period design, and as stress test input for capacities dependent on cooling water (IX.2, IX.5).

This three-part classification is used consistently throughout the analysis in this report.

Four rules apply in all areas where design is based on climate data.

- 1 For the four most important indicators, measured values, rather than model outputs, serve as the starting point.** For temperature, the number of days reaching 30 °C, spring frost and the vapour pressure deficit, none of the runs from the domestic climate models reach what has already been measured. Both sets of domestic projections show this for temperature and the number of days reaching 30 °C (H.2). Where a standard or funding condition refers to the range of the models, the lower limit of that range is the smallest value still conceivable. However, planning must be based at least on the measured values. This rule does not apply to intense rainfall, the duration of dry spells, or the number of days reaching 35 °C, as the model does not underestimate these values.
- 2 Preparedness must be sized for the unfavourable but realistic scenario.** Designing for the mean value consistently underestimates the expected damage, as climate-related damage grows at an accelerating rate with warming (G.5). The basis for sizing is Band C of Section VIII.6, i.e. two consecutive years of drought characterised by high temperatures, low river flows and reduced power station output, which may also be accompanied by spring frost damage for reasons unrelated to the dry winter. This is not the most likely scenario, but it is a realistically possible one.
- 3 Facilities that will remain in operation after 2050 must be designed for at least 2 °C of global warming, with a 2.5 °C stress test.** This applies in particular to long-lived infrastructure: water management works, energy facilities and healthcare facilities (VII.1). Designs cannot rely on a more favourable halt to warming as a cost-saving measure (VII.2). It is advisable to enshrine the planning level in legislation to ensure that all sectoral plans and standards refer to the same level. France, for example, laid down its own reference warming trajectory in a decree in January 2026.¹⁸³

- 4 It is too early to scale back cold-weather preparedness.** In 2026, temperatures ranging from -18.3°C to $+42.0^{\circ}\text{C}$ were recorded within a single year (II.4). Warming reduces the frequency of cold extremes but does not eliminate them; therefore, scaling back winter and frost protection capacity in the coming decade is premature. We do not quantify cold-related exposure and damage; therefore, this finding merely indicates the direction and cannot be applied as a design rule (II.4).

IX.2 Water management

Groundwater levels are falling at 94 per cent of the wells in the national main well network, and at 98 per cent of those east of the Danube. In August 2026, 79 per cent of the wells were at the lowest level in their own series, and the abundant winters since 2014 have not raised levels back to their previous peaks. In Western Transdanubia, however, there is no consistent downward trend (III.1). Precipitation during the winter half-year has not decreased, yet groundwater only recharges during winters with abundant rainfall. The summer discharge of the Körös and Maros rivers in 2026 was the lowest recorded since 2000. The level of deeper confined groundwater has been falling since 2019, and the cause cannot be determined because a significant proportion of water abstraction is unmeasured (III.2).

- 1 Water abstraction must be made measurable even where it is not currently measured.** This is the least costly step and a prerequisite for any further water management decisions. As long as water abstraction remains unknown, it is impossible to determine how much of the decline in reserves is due to climate change and how much to water use (III.1, III.2). Without measurement, both the rejection of irrigation restrictions and the expansion of irrigation based on groundwater are unfounded.
- 2 Water from the winter half-year must be retained in the landscape.** Groundwater is replenished only during winters with abundant rainfall, and a missed abundant winter cannot be compensated for by an average one (III.1). The drainage canal network diverts an average of around 1.77 billion cubic metres of water annually from drought-prone lowlands, even outside periods of waterlogging (IV.3). Water retention can be organised primarily through land-use measures at the scale of the Great Plain. Here, water management and agriculture cannot be planned separately, since the primary sites for water retention are precisely the areas that change land-use category because they are not economically viable as arable land in the long term (IX.3).

- 3 The sequence of interventions must be determined on a regional basis.** The starting point for this sequence is the combined series of river discharge, groundwater level and average crop yield, not precipitation alone. In the Körös–Sárrét region, all three are deteriorating simultaneously, while in Western Transdanubia, none of them are (III.1).
- 4 The summer of 2026 is the reference dry period for the design of reservoirs and irrigation systems.** The longest dry spell (consisting of days with less than 1 mm of rainfall) during the growing season averaged 30.2 days across the ten weather stations that have been recording data since 1901, and 53 days in Szeged (II.2). Whether this year turns out to be an outlier or a turning point, the design must cover it.
- 5 Abstraction from confined groundwater must be measured, and the protection of drinking water sources must be adapted accordingly.** Confined groundwater accounts for around one-third of the drinking water supply (III.2), and the consequences of a mistaken ‘all is well’ assessment could only be rectified over the course of decades (III.2). Of the 1,746 operational drinking water sources, 208 are highly climate-sensitive, the majority of which rely on confined groundwater shallower than thirty metres (III.5).
- 6 The statutory order of water restrictions must also be incorporated into capacity and investment planning.** The Water Management Act stipulates the order in which water demands may be met; restrictions are applied in reverse order and, with the exception of water use for subsistence purposes, are imposed without compensation (V.4). Investment planning currently does not align with this order, and the associated risk therefore lies in unpredictable allocation.
- 7 Different flood preparedness measures are required on the Danube and the Tisza.** Days of the highest, third-level flood alert have practically ceased on the Tisza, remain essentially unchanged on the Danube, and are increasing at Mohács (III.3). Both river basins are international, but the Danube is also fed by Alpine snow and ice reserves, while the Tisza is fed by Carpathian precipitation. In the Tisza catchment, fewer but more intense rainfall events tend to cause flash floods and inland flooding – this is our own conclusion. In September 2024, for example, within the space of a month there was flooding on the Danube while the Tisza was at low flow (II.4).

- 8** By 2050, planning for the Danube must account for higher flows in winter and more uncertain flows in summer. The volume of Alpine glaciers will decrease by about half by 2050, so the reserve for hot, dry summers is shrinking (VII.5). In planning for cooling water, navigation and drinking water supplies, the summer of 2026 serves as the baseline scenario for stress testing.

IX.3 Agriculture and rural development

The summer vapour pressure deficit in 2021–2025 exceeded the 1971–1980 average by 39 per cent, and the 28 model runs in the national projection database do not reflect this increase (II.2). The risk of spring frosts is not decreasing, as bud burst has moved forward by twelve days, while the date of the last spring frost has remained unchanged (II.3). Maize is the most sensitive major crop: yield losses exceeding 20 per cent have all occurred during summers warmer than normal, while the average yield is just as closely linked to rainfall during the growing season as it is to summer heat (V.2).

- 1** The vapour pressure deficit (the air's capacity to hold water vapour) should be included **among the indicators** used in agricultural planning **and subsidy criteria**. It is not currently included in the official set of climate indicators, even though this parameter provides the strongest observational signal. The indicator must be precisely defined, as the vapour pressure deficit is a quantity derived from measurement, while the calculated evaporative demand (ET0) is a calculated indicator, and the two are not interchangeable (II.2).
- 2** The expansion of irrigation is contingent upon the water balance and water quality. Expansion based on groundwater cannot be justified before water abstraction has been measured (IX.2). In much of the Great Plain, groundwater has a relatively high salinity, and the area at risk of secondary salinisation is of the order of 400,000 hectares – this figure is known from secondary sources (IV.3). Furthermore, irrigation is expensive and, in summer, once a shortage has arisen, it is a reactive measure which, unlike winter water retention, does not replenish water reserves. In our view, it pays off in the long term for high-value crops; therefore, the location of irrigation expansion should be tailored to where these crops are grown, rather than to current arable land.

- 3 It is too early to reduce frost protection capacity.** The number of days with frost per year is decreasing, but this is an unsuitable indicator for decisions on plantation establishment and variety selection. The number of damaging frosts occurring after bud burst was at its highest in the measurement series between 2021 and 2025 – this is a five-year observation, not a trend (II.3).
- 4 When selecting crop varieties and cultivation methods, heat tolerance and frost tolerance must be considered together.** Hungarian agriculture has to cope simultaneously with winter cold, spring frosts and summer drought; therefore, the challenge cannot be addressed by relying solely on heat-tolerant varieties (IV.3).
- 5 The extent of damage the damage mitigation scheme can cover must be assessed.** Between 2012 and 2024, damage mitigation payments totalled 162.8 billion forints, 70 per cent of which related to drought damage; in the drought year of 2022, only 80 per cent of eligible claims were paid out (IV.3). In our view, two consecutive years of drought (IX.1) would test the system's capacity. Damage mitigation must therefore also be linked to the suitability of the land for cultivation. To this end, it is necessary to identify at national level where arable farming is justifiable in the long term, and where it is not; in the latter cases, support should be provided for a change of land-use category rather than compensation for recurring losses. Areas taken out of arable farming could serve as water retention sites (IX.2).
- 6 Droughts developing over a period of a few weeks must be measured.** International literature identifies rapidly developing soil moisture deficits as the main cause of crop damage; however, domestic indicators do not measure this. This would require a root-zone soil moisture series recorded every five days (H.4, VIII.7).

IX.4 Forestry

Forest climate classes have shifted towards drier conditions: the proportion of beech forest climate areas fell from 5.5 to 2.1 per cent, while that of hornbeam-oak forest areas fell from 28.9 to 21.0 per cent (II.6). In the assessment based on grid points, 23.2 per cent of the cells have shifted to a drier class; there has been no shift towards a wetter climate. The shift occurs in contiguous blocks: in the Nyírség and the Upper Tisza region,

in South-Western Transdanubia and in two smaller areas of the Southern Great Plain.

- 1 Afforestation and tree species selection should be based on the drier climate class.** Both domestic assessments end in 2010, so the warming that has occurred over the past fifteen years is not yet reflected in them (II.6). The trend and spatial pattern can be used for planning purposes; however, the two assessments differ in the proportions of the classes.
- 2 The forest climate class map must be updated with data from after 2011.** The update is a data exercise that would base planting decisions on current conditions.

IX.5 Energy

In the summer of 2026, the Paks Nuclear Power Station had to reduce its output due to record-low flows in the Danube and temperature regulations governing the discharge of cooling water. According to public statements, on 29 July, for the first time in the power station's history, an entire unit was shut down due to low flows, and on 1 August, total output fell to 476 MW (IV.4). Meanwhile, a hot, dry summer increases electricity demand (VII.7).

- 1 The reduction in output due to low flows must be incorporated into the design analyses of the electricity system.** A second condition should be added to the existing sensitivity analysis: the load reduction caused by low flows, with a frequency derived from the measured water flow data (IV.4). This is an operational decision and does not require any investment. The costs of the two possible errors are very different. If the condition proves to be unnecessary, the cost is merely that of an additional calculation. If, however, it is omitted, the shortfall may manifest as a unit outage during periods of peak demand caused by the simultaneous occurrence of high temperatures and low flows (G.5).
- 2 The assumptions underlying water management licensing and energy planning must be harmonised.** In the environmental permit for the Tiszaújváros power station, the water authority states that, due to low flows, it does not accept responsibility for a fully reliable water supply, while energy planning treats the same capacity as guaranteed (IV.4). This gap in responsibility must be eliminated.

- 3 For new or expanding capacities dependent on cooling water, the summer water flow of 2026 must be used as a stress test.** At Paks, the lowest summer water flow was 726 m³/s, half the median of the summer minima over the thirty-seven-year series (VII.5). On 8 October, the daily average fell to 613 m³/s (the lowest instantaneous value was 607 m³/s), which is the lowest daily value in the series dating back to 1990 and 56 per cent of the median of the annual minima for 1990–2025 (preliminary, operational data). By 2050, the Danube’s summer reserve will shrink as the Alpine glaciers retreat.
- 4 Peak demand planning should take into account the simultaneous occurrence of heatwaves and low flows.** Due to their common underlying cause, these two risks are not independent: the probability of their simultaneous occurrence is higher than would be suggested by the assumption of independence (VII.7, VIII.3).

IX.6 Health and social care

Between 2011 and 2023, heatwaves resulted in an average of 814 excess deaths per year, with extremes ranging from 28 to 1,741 (IV.1). According to a European estimate, in 2024 there were 1,668 heat-attributable deaths per million people aged 75 and over, compared with 19 among younger people (IV.1). The heat burden on this age group in 2021–2025 is 3.2 times that of the 1991–2020 period, primarily because the number of extremely hot days has increased (IV.2). The number of extremely hot days has increased most significantly in Csongrád-Csanád, Békés and Bács-Kiskun counties: in Csongrád-Csanád, from 5.5 to 18.2 per year.

- 1 Preparations for heatwaves should focus on four target groups: the elderly, those with chronic conditions and bedridden patients, pregnant women and young children, and outdoor workers.** The vast majority of heat-related deaths occur among those aged 75 and over; therefore, the primary indicator for alerts and care provision should be the heat burden on this age group, rather than the national number of extremely hot days (IV.1, IV.2). For the other three groups, the harm manifests primarily as illness, workplace accidents and adverse obstetric outcomes, and there is no domestic monitoring of these (IV.1). This requires heat protection measures and heat contingency plans for social, healthcare and childcare facilities; a review of medication regimens for elderly patients with chronic conditions before the summer; and inspection of compliance with occupational heat regulations during heat alerts.

- 2 The heat alert system must not be dismantled.** If the impact on mortality is low in certain years, this may be the result of adaptation; scaling back protective measures at such times would have an immediate adverse effect (IV.1).
- 3 The link between heat and mortality must be continuously monitored.** The domestic mortality series based on alert days ends in 2023. This must be continued, and mortality data must be available even during heatwaves (IV.1). Emergency care data must also be monitored as a heat indicator – the only nationwide study series ends in 2017 (IV.1).
- 4 The heat risk map must be updated.** The official heatwave vulnerability layer is based on data from the 2005–2014 period, while the population projection is from 2011 (IV.2). This is a data update, not model development, and is therefore quick and inexpensive.
- 5 Alert systems and contingency planning should be based on the daily mean temperature and tropical nights.** These two thresholds are decisive for the burden on the healthcare system, not the daily maximum temperature (II.1). Between 2021 and 2025, the number of nights on which the temperature did not fall below 20 °C exceeded the 30-year average by around four and a half nights per year.

IX.7 Buildings, settlement structure and infrastructure

Buildings, settlement patterns and networks have a service life of between fifty and one hundred years; they must therefore be able to withstand even extremes that are still rare today. The national average number of extremely hot days (daily maximum ≥ 35 °C) between 2021 and 2025 was 8.5 per year, compared with 2.8 for the period 1991–2020 (II.1). Precipitation on the wettest days has increased by more than 20 per cent, and in 2026 temperatures ranging from -18.3 °C to $+42.0$ °C were recorded within a single year (II.4). According to a European survey, in

2012, 25.8 per cent of Hungarian homes could not be kept sufficiently cool in summer, rising to 32.8 per cent in low-income households.¹⁸⁴

- 1 Mandatory summer overheating requirements are needed for new and substantially refurbished buildings.** The EU Energy Performance of Buildings Directive requires adaptation only to be considered; the risk of overheating is an optional indicator in the energy performance certificate.¹⁸⁵ The actual scope for action therefore lies in the national transposition. In England, a mandatory requirement has been in place since 2022 to limit summer heat gain in new residential buildings, and mechanical cooling may only be considered as a last resort.¹⁸⁶ The climatic input for this requirement should be the measured value specified in Section IX.1.
- 2 Shading, night-time ventilation and passive cooling should also be eligible for support under renovation grants for existing buildings.** The majority of the building stock will still be standing in 2050. According to an independent risk assessment by the United Kingdom, 92 per cent of existing homes could overheat at 2 °C of warming.¹⁸⁷ As there are no domestic estimates, we use the above housing data as an indicator of domestic exposure.
- 3 As a priority, buildings providing care for people aged 75 and over must be made heat-resistant, and cooled communal spaces must be designated in municipalities.** Hospitals, care homes and social care institutions cater for the age group with the highest heat burden (IV.2). Spain operates a separate budget, allocated via the regions, for the heat-proofing of public buildings and the provision of cooling centres, and is planning a national network of cooling centres.¹⁸⁸ No assessment of the impact of the Spanish programme is yet available.
- 4 Climate data for building and structural design must be aligned with measured values.** The second-generation European structural design standards require climate change to be taken into account for snow and wind loads. The value of this factor is set out in the national annex, while the first generation must be phased out by early 2028.¹⁸⁹ This decision will shape domestic design standards for decades to come and must therefore be based on measured changes.

- 5 In urban planning, paved surfaces must be reduced, while green and water surfaces must be increased.** Permeable surfaces simultaneously mitigate heat and reduce the runoff from heavy rainfall, while also retaining the water of the winter half-year within the landscape (IX.2). In Germany, since 2024, all public service providers have been required to take the urban heat island effect and flash floods into account and to endeavour to remove unnecessary paving.¹⁹⁰ We examined the extent of the urban heat island effect in Hungary at monitoring stations and using the KLIMADAT modelled urban layer: On average between 2016 and 2025, there were more than three times as many tropical nights in the inner city of Szeged as in the outlying areas; in the inner districts of Pest, the modelled value was more than seven times the national average (IV.2).
- 6 Climate risk assessment should be mandatory for facilities built using public funds or EU funding that are expected to operate for more than ten years.** The EU taxonomy provides a three-step method for this, according to which the risk must be assessed across the full range of scenarios for assets with a lifespan of more than ten years.¹⁹¹ For domestic application, the input should be the two warming levels specified in Section IX.1: at least 2 °C, with a 2.5 °C stress test.
- 7 A climate-based review of building and infrastructure design standards must be mandated, with a deadline and a designated responsible party, for both extremes.** The design of roads, railways, utility lines and networks must simultaneously account for higher temperatures, more intense precipitation and persistent winter cold (IX.1). In 2021, Spain enacted legislation requiring the adaptation of design standards to climate change, but without specifying a deadline or assigning responsibility; since then, building regulations have only been amended for the purpose of reducing emissions.¹⁹²

IX.8 Local authorities, urban planning and disaster management

The risks of heatwaves, flash floods and water supply disruptions materialise in settlements, and it is there that they are most unevenly distributed. The number of extremely hot days has increased most significantly in the southern and eastern counties of the Great Plain (IV.2); flash floods pose a danger in small catchment areas in mountainous and hilly regions

(III.5); and water supply is most vulnerable in settlements reliant on shallow aquifers.

- 1 Municipal heatwave plans must first be updated in the most affected counties.** The number of extremely hot days has increased most significantly in Csongrád-Csanád, Békés and Bács-Kiskun counties, to more than three times the 1991–2020 average (IV.2). However, according to a county-level analysis covering 2015–2025, the average excess mortality during weeks of intense heatwaves is highest in Tolna, Baranya and Jász-Nagykun-Szolnok counties (26–35 per cent), while in the three counties with the highest number of extremely hot days, it stands at 20–25 per cent.²²² The ranking should therefore be determined by these two indicators together; we did not examine the role of local preparedness.
- 2 In settlements within small catchment areas at risk of flash floods, rainwater drainage must be adapted to the measured changes.** The official system classifies 367 out of 2,120 mountainous and hilly catchment areas as highly endangered, and 539 as considerably endangered (III.5). Precipitation on the wettest days has increased by more than 20 per cent, while the number of rainy days has hardly changed (II.4).
- 3 Planning for municipal water supply should take into account the climate sensitivity of drinking water sources.** Of the approximately 1,500 settlements assessed within the supply areas of the ten major water utility providers, 421 fall into the ‘highly sensitive’ category (III.5).
- 4 Disaster preparedness exercises should be based on a combined stress year.** Exercises should simultaneously address drought, heatwaves, low river levels and disruptions to the energy supply. The summer of 2026 has already demonstrated this combination of events (VIII.6, VII.7). Preparations must also take into account the possibility that both flooding and low river levels may occur in the same month (II.4).
- 5 The twelve warning signs must be assessed annually.** Between 2027 and 2031, the signs will indicate which of the three possible trajectories for the coming decade the country is heading towards, before the consequences materialise (VIII.6, VIII.7). Responsibility for the assessment must be assigned.

- 6 The municipal adaptation plan must be based on a local stress test.** The test uses the levels set out in Section IX.1 and data measured during the summer of 2026 to assess where the municipality will be affected by heatwaves, water shortages or flash floods. In the Netherlands, the stress test, risk assessment and implementation programme have been carried out in all 45 working regions, while in Germany the federal states designate who is to draw up a risk-based adaptation concept for each municipality and district.¹⁹³

IX.9 Finance, budget and EU funds

There is no official national economic damage account, and the only official macro-level estimate is already sixteen years old (V.1). Between 1980 and 2024, damage caused by weather and climate extremes amounted to 12.8 billion euros; 78 per cent of this occurred in just five years, and only 4.8 per cent of the damage was insured (V.2). The 2022 drought caused crop losses of around 2.4 billion euros across six major arable crops.

- 1 An official national economic damage account must be drawn up.** This would form the basis for budgetary planning, applications for funding from the Cohesion, Rural Development and Solidarity Funds, and the justification for the use of ETS revenues (V.1).
- 2 Budgetary reserves should be planned with a view to rare years of major losses.** Losses are concentrated in a few extreme years, with the median annual loss amounting to 14 million euros (V.2). Reserves calculated on the basis of an average year are insufficient in years of major losses.
- 3 International loss figures should only be used in conjunction with domestic data or their sources.** There are no Hungarian estimates to back up statements such as ‘water shortages could cost 7 per cent of GDP’ (V.1).
- 4 Financial stress tests must also be extended to cover physical climate risks.** The Hungarian National Bank’s 2025 climate stress test examined transition risk; the 2026 report does not include a physical risk stress test (VII.7). According to the European Environment Agency, existing financial stress tests are likely to underestimate mutually reinforcing, cascading risks.

- 5 Concurrent risks must not be treated as independent of one another.** Drought, heatwaves, low flows and disruptions to energy supply can all be traced back to a common cause; therefore, the probability of their occurring together is greater than if they were independent events (VIII.3).
- 6 In addition to the damage account, a damage financing strategy is also required, which sets out in advance who will pay for major damage and from what sources.** Of the damage, 4.8 per cent was insured (V.2). According to a 2021 European model, in the event of a flood with a 1 per cent annual probability (referred to in the source as a ‘once-in-a-century’ event), domestic reserves would cover approximately 175 million euros, the EU Solidarity Fund approximately 196 million euros, while approximately 936 million euros would remain uncovered.¹⁹⁴ We consider that the uncovered portion currently awaits an ad hoc budgetary decision.
- 7 A compulsory, standardised insurance scheme with a disaster damage surcharge, backed by state reinsurance, should be examined.** In Spain, all property insurance policies pay a surcharge to a state-run claims-paying body, which, following the 2024 floods in Valencia, paid out or set aside €5.16 billion to cover 207,527 claims.¹⁹⁵ The French system has operated on a similar principle since 1982, covering 97 per cent of homes, and the state guarantee has had to be called upon only once. However, in 2026, the French Court of Auditors concluded that the reinsurer’s reserves had been depleted due to drought damage, and that in the medium term, annual calls on the state guarantee of around one billion euros were likely.¹⁹⁶ Taken together, these two examples show that the system pays out claims quickly, but can only cope with rising drought damage if both premiums and prevention measures are adjusted accordingly. The Spanish system does not cover drought or heatwaves, and therefore cannot on its own serve as a model for managing domestic drought damage (IX.3).
- 8 Compensation and force majeure support should be conditional upon reinforced reconstruction.** In France, a pilot programme finances a post-flood vulnerability assessment and up to 80 per cent of the reinforcement works, and the Court of Auditors recommends its extension.¹⁹⁷ This helps to mitigate the risk of having to pay compensation multiple times for the same vulnerability.

- 9 Preparations must be made for EU adaptation funding becoming conditional on a national adaptation plan.** According to a summary by the European Parliament's Research Service dated September 2026, the forthcoming EU framework would make Member States' resilience plans a condition for access to EU funds.¹⁹⁸ This is still a proposal, not a decision. To date, Hungary has received a total of 37.6 million euros from the EU Solidarity Fund following two floods, out of 1,238 million euros in damage; the fund covers community-level recovery, but not private damage.¹⁹⁹
- 10 Budgetary allocations for adaptation must be tagged.** This makes it possible to track how much funding is allocated to adaptation and to compare it with the damage account (point 1). Spain stipulates by law the proportion of the budget earmarked for climate-related purposes and allows a portion of the revenue from the auctioning of emission allowances to be spent on measures to reduce vulnerability.²⁰⁰

IX.10 Statistics, data management and knowledge base

Data on hazards are updated annually; however, official data on the other two risk factors – exposure and vulnerability – have not been updated for a decade (IV.2). Some key indicators are not measured at all at present: a significant proportion of water abstraction, confined groundwater extraction and soil moisture in the root zone. Actual evaporation is measured only at a few research stations.

- 1 The exposure and vulnerability data layers need to be updated.** The vulnerability layer of the national adaptation GIS dates from 2005–2014, its population projection is from 2011, and its climate layer is based on the previous model generation; furthermore, it does not include the 1991–2020 climate norm, which has already been finalised (IV.2).
- 2 Decadal climate prediction must be incorporated into 5–10-year planning cycles.** Such a product is already available for the coming decade. It tracks summer temperatures well, largely because of the warming trend, but does not predict precipitation; therefore, it can only be used where skill can be shown (H.3).

- 3** A public, explicitly defined list of climate thresholds must be adopted; in other words, it must be established which climate thresholds the public administration wishes to avoid exceeding. At present, the public administration does not specify which climatic thresholds it wishes to avoid; consequently, every risk analysis is based on unstated value choices. The twelve thresholds in Annex A constitute a proposal to this end. The twelfth threshold cannot currently be measured, and its very inclusion indicates that the indicator is missing.
- 4** **Data stewards for the warning signs must be designated.** Of the twelve indicators, there is currently no designated data steward for measuring soil moisture in the root zone (VIII.7).
- 5** **Official national climate products must be updated to the new model generation.** The official system currently provides projections based on regional models from the previous model generation, two emission scenarios, and the periods 2021–2050 and 2071–2100 (VII.8). Until the update is completed, the official 2050 temperature values should be treated as lower estimates (VII.4).

IX.11 Meteorological measurements and climate modelling

The strongest observed sign of drying is the increase in the vapour pressure deficit (II.2); however, the measurement and modelling chain is weakest precisely for this quantity. The trend in the vapour pressure deficit, as measured from air humidity, is currently confirmed by a single source: the official surface network data grid. Boundary layer humidity is measured twice daily by two radiosonde stations, in Budapest and Szeged.²⁰¹ The projection database used for impact assessments does not

take air humidity from the models but estimates it from temperature (II.2), while soil moisture in the root zone is not measured (IX.10).

- 1** The measurement of air humidity must be expanded in both space and time. Surface air humidity is measured by the HungaroMet network of stations, and high-quality grid-point data has been available since 1971 (II.2). The expansion therefore primarily concerns the boundary layer and sectoral measuring stations. Humidity sensors at sectoral and voluntary stations must be calibrated against official stations before they can be used for trend analysis. Boundary layer humidity could be monitored more frequently, or even continuously, through regular, pre-scheduled flights by meteorological drones. The practical feasibility of this must be investigated. The World Meteorological Organisation's 2024 demonstration campaign tested a standardised data format and real-time data transmission; in a Swiss campaign, drone-based temperature measurements met the medium accuracy requirement, while humidity measurements met only the minimum accuracy requirement, although the development of the equipment is ongoing.²⁰¹
- 2** A national monitoring network is required for soil moisture in the root zone, with a designated data steward. At present, national soil moisture trends cannot be estimated from official measurements, only from models (II.2). KITE's agrometeorological network, comprising nearly 600 stations, measures soil moisture and air humidity at several depths; however, the length and quality of these measurement series are not verified. The network is a prerequisite for measuring droughts that develop over a few weeks (IX.3) and for one of the warning signs (IX.10). Existing sector-specific monitoring networks (such as the KITE network) must be integrated into a national system, together with quality assessment of their data series. The long-term maintenance of existing eddy covariance stations is necessary for measuring actual evapotranspiration.
- 3** The vapour pressure deficit in impact assessments must be calculated from the regional models' own air humidity data. The models' humidity data must be corrected against measured reference values before being incorporated into the chain, as this is the only way to determine whether the models themselves also underestimate atmospheric drying (II.2). If so, the research direction of domestic regional modelling must be reviewed, and, as part of this process, decadal prediction must also be incorporated into domestic modelling practice (IX.10).

- 4** The two domestic projection sets must be regularly compared with observed data in a joint, public test. FORESEE-HUN and KLIMADAT are consistent in their temperature projections, which remain below observed values, but they differ in terms of winter temperatures and the number of days with precipitation (H.2). Planners can use them reliably if the data stewards report annually, for the same time periods and relative to their own observation series, where the range of the simulations overlaps with the measurements. In the case of KLIMADAT, this requires the reporting of values per run and the correction of the number of rainy days; in the case of FORESEE-HUN, it requires justification for the extremely narrow range covering the coming decade. A joint test by the two modelling groups would also demonstrate where domestic climate products reinforce one another. When transitioning to regional runs based on the new generation of models, this same test must be repeated, and the consistency of the aerosol forcing in the regional models with the driving global model must be verified (H.2).

IX.12 Adaptation planning and governance

The actions outlined in the previous sections arise in specific sectors, but their implementation requires a common framework: a designated lead, funding, a timetable and regular review. There are established European models for most of the elements listed below.

- 1** An adaptation strategy must be accompanied by a five-year implementation programme, with a budget and designated responsible parties for each action. Spain's first adaptation plan was drawn up without its own budget, and the evaluation of the plan identifies this as the main weakness of its implementation. The 2021 Climate Act already stipulates five-year work programmes. Germany stipulates a ministry responsible for each objective, measurable indicators, and the collection of data on damage and expenditure.²⁰²
- 2** A national climate risk report should be produced every five years, and the implementation programme should be aligned with this. The Spanish Climate Act requires a risk report at least every five years; in the United Kingdom, the fourth independent risk assessment was published in 2026.²⁰³ The report may be based on the data layers set out in Section IX.10 and the annual assessment of warning signs (IX.8).

- 3 A single planning warming level must be established, to which all sectoral plans and standards refer.** The French decree specifies the trajectory for the country's territory; therefore, its values cannot be directly compared with the global levels set out in Section IX.1. The decree does not in itself impose any new obligations; its binding force derives from its gradual incorporation into sectoral regulations.²⁰⁴
- 4 The order of priorities must be established according to public, pre-defined criteria.** The Spanish work programme ranks the most pressing items in the national risk assessment according to a simple matrix of criteria: key impact, urgency, severity, feasibility, legal obligation and cost-effectiveness.²⁰⁵ In the domestic context, the risk ranking from this analysis could serve as the input for the matrix.
- 5 Climate risk must be assessed within a national risk picture shared with other hazards, with a designated coordinating officer.** According to a British security policy analysis, one of the structural flaws in governments is that climate and security risks are managed by separate ministries, and no one sees the whole chain of knock-on effects (VIII.4).¹⁷⁴ The EU preparedness report recommends a comprehensive risk assessment covering all hazards and threats (VIII.5).¹⁸² Domestic application is this analysis's own proposal.

IX.13 Overview

field	Most important action	Nature	Basis
All fields	design based on measured values for the four key indicators; for facilities operating beyond 2050, at least 2 °C, with a 2.5 °C stress test	Rule	H.2, VII.1
water management	making water abstraction measurable; retention of winter-half-year water, sequenced region by region	data; preparation of investment	III.1, III.2
agriculture	Inclusion of the vapour pressure deficit among planning and support indicators; water balance and water quality conditions for irrigation expansion	Rule	II.2, IV.3
forestry	planting and selection of tree species for the drier climate class	Rule	II.6
energy	incorporation of the reduction in power output during low flow into system design analyses	operation	IV.4

field	Most important action	Nature	Basis
healthcare	heat burden among those aged 75 and over as an indicator for alerts and care provision; continuous mortality data	rule; data	IV.1 , IV.2
buildings, settlement structure, infrastructure	summer overheating requirements for new and refurbished buildings; mandatory climate risk assessment for public works projects with a lifespan of more than ten years	Rule	II.1 , II.4 , IV.2
local authorities, disaster management	municipal heatwave plans in the most affected counties; local stress tests; exercises for a year of combined stress	operation	IV.2 , VIII.6
Finance	national economic damage account; damage financing strategy and compensation mechanism; physical risk stress test	data; rule	V.1 , V.2 , VII.7
statistics and data	updating vulnerability layers; threshold list; incorporation of the decadal prediction	data; rule	IV.2 , H.3
Meteorology	expansion of air humidity measurements; national soil moisture measurements; calculation of the vapour pressure deficit from the air humidity in the models	data; operation	II.2 , H.3
adaptation planning and governance	five-year implementation programme with a budget and designated responsible parties; five-yearly risk report; a joint risk picture covering all hazards	rule; operation	IX.1 , VIII.4 , VIII.7

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The thresholds used

#	Threshold	Base	Probability
K1	Number of days with a daily mean temperature of ≥ 25 °C	Observation	quantifiable
K2	Tropical nights ($T_{min} \geq 20$ °C)	Observation	quantifiable
K3	Hot day ($T_{max} \geq 35$ °C) during a critical phenological stage	observation + projection	quantifiable, with phase definition
K4	Frost risk window (bud burst → last frost day, daily minimum < 0 °C)	Observation	limited – see II.3
K5	Water balance deficit during the growing season	Observation	quantifiable
K6	Winter half-year recharge threshold (~185 mm, Homokhátság; to be measured by landscape unit)	Observation	quantifiable
K7	River low-flow threshold (window specified)	Observation	quantifiable
K8	Groundwater level threshold (failure of shallow wells)	Observation	quantifiable, spatially variable
K9	Days with cooling water constraints	observation + operational data	qualitative
K10	Damage mitigation system coverage limit	financial time series	qualitative , due to missing data
K11	Concurrence of drought and heatwave during the growing season	Observation	qualitative – joint probability cannot be estimated
K12	Pentad-scale drop in soil moisture in the root zone (from the 40th to the 20th percentile during the growing season)	observation, not currently in existence	cannot be estimated until a domestic series is available

B ANNEX B

Reading instructions

- 1 The **reference period** and **window** are shown next to each figure. Two figures with different references cannot be compared directly. Threshold indices are calculated at each grid point and only then averaged. The reverse order yields a different result.
- 2 We do not use return periods.
- 3 We do not report linear trends fitted to short time windows as design values.
- 4 Where a ‘qualitative’ label is used, no numerical probability is available – there is no hidden numerical value behind the descriptive label.
- 5 Where the literature is divided, we report the divergence rather than calculating a mean value.
- 6 The **model-side mean temperature** is the average of the daily maximum and minimum, as the supplied data set does not contain a daily mean temperature. As a deviation (anomaly), this approximation cancels out, as the reference climatology is compiled in the same way. **However, this series cannot be cited as an absolute temperature level.** The model deviations in Section II.1 should therefore be interpreted as deviations, not as temperature values.
- 7 **Multiple testing.** If we run many trend tests, some will fall below 0.05 purely by chance – roughly five out of a hundred tests, even if there is no real change anywhere. For this reason, we group the observational and hydrological trend tests into a single family and divide the threshold by the size of the family (Bonferroni correction). The family consists of 104 tests; the corrected threshold is 0.05/104, which is approximately 0.0005. Only results that meet this threshold are classified as ‘significant’. Those that do not meet it are reported descriptively: with the magnitude of the change, the confidence interval and the p-value.

statement	p	classification
vapour pressure deficit (VPD), all four indicators, 1971–2025	< 0.00001	reaches
daily temperature range, annual and summer, 1971–2025	0.00002 / 0.00003	reaches

statement	p	classification
annual vapour pressure deficit, 1991–2025	0.00012	reaches
August trend in groundwater level	0.00011	reaches
confined groundwater level, 2019–2026 period (data-driven break year, III.2)	0.0002	reaches, but only with the year 2026 included (without it: 0.0014)
days per year with a vapour pressure deficit above 1,500 Pa, 1991–2025	0.00062	does not reach this level; descriptive form
number of days with sub-zero temperatures per year, 1971–2025 (confidence interval does not include zero)	0.0012	does not reach this level; descriptive form
advancement of bud burst, heat sum-based indicator	0.0049	does not reach this level; descriptive form
number of dry days in summer, 1971–2025	0.037	not reached, directional indicator

Three comments are required regarding the table. The first concerns the nature of the correction. The tests are not independent of one another, as they run on the same grid, in nested windows, while the vapour pressure deficit and the temperature fluctuation are physically a single signal. The Bonferroni correction is therefore stricter than necessary and works in the direction of the second type of error (G.5). Results that fail this test should not be regarded as noise, but as insufficiently substantiated. The second comment concerns the size of the test family. The membership of two items is an estimate; therefore, the size of the family is known to an accuracy of roughly eight tests. The classifications in the table do not change within this range, because the uncertainty of eight tests in the size of the test family does not shift the corrected threshold enough to cause the classification of any result to change. The third point concerns the boundary of the family. Calculations from other data providers, such as the cross-validation carried out using the official KLIMADAT service, are not members of the family. The crop damage comparison in Section V.2 is based on a separate, pre-defined family of nine tests, with its own corrected threshold.

This annex explains the technical terms used in the analysis. Where the terminology used in the analysis deviates from official meteorological convention, the entry indicates this – this is a deliberate choice made to improve readability, not a typographical error.

Temperature thresholds

- **Hot day and extremely hot day:** according to HungaroMet’s terminology, a hot day is a day on which the daily maximum temperature reaches 30 °C, while an extremely hot day is one on which it reaches 35 °C. This analysis follows this terminology. Threshold K3 in Annex A restricts the 35 °C limit to the critical phenological phase. The planning minimum rule (H.2) applies to hot days, but not to extremely hot days.
- **Tropical night:** a night on which the temperature does not fall below 20 °C (K2). From a health perspective, this is more important than the day-time peak, as the absence of a night-time cool-down hinders the body’s recovery.
- **Daily mean, daily maximum:** the analysis uses two different heat indices, which are not interchangeable. K1 is based *on the daily mean temperature* (≥ 25 °C, which is the indicator used in health planning), while K3 is based *on the daily maximum* (≥ 35 °C). Their values cannot be compared.

Interpreting the figures

- **Anomaly:** the difference from the average of a reference period; it is not a temperature value. ‘+1.7 °C’ means that it is this much warmer than the reference – not that the temperature is 1.7 degrees.
- **Reference period:** the period, usually spanning 30 years, against which deviations are measured (typically 1991–2020 in this case). Two **figures with different reference periods cannot be directly compared** – which is why the reference period is stated alongside each figure.
- **Time window:** the period under review (e.g. 2006–2025). The choice of time window significantly influences the resulting value, which is why it is always specified.
- **Grid point, grid average:** the country’s territory is covered by a regular grid of points (1,233 points); the grid average is the mean of these. A grid

average may mask the fact that the load is spatially uneven – which is why we also show a map where possible.

- **Threshold index:** an indicator that reports the number of times a threshold value is exceeded, rather than the value itself: extremely hot days, tropical nights, frost days, dry days. It is always calculated at each grid point and only then averaged nationwide – the reverse order omits values close to the threshold (Annex B/1.). The threshold index is sensitive to the threshold (the same indicator yields different values for ‘dry day’ thresholds of 1.0 mm and 0.1 mm), so the value is quoted together with its threshold.
- **Homogenised data:** a series of measurements from which jumps resulting from station relocations or instrument replacements have been filtered out retrospectively. This makes old and new measurements comparable.
- **Median: the middle value – half the measurements are below it and half are above it.** It is less sensitive to outliers than the mean.
- **Return period** (‘hundred-year event’). We do not use this in our analysis. Such a term assumes that the climate is constant – in a changing climate, it is misleading because ‘hundred-year’ events are actually becoming more frequent.

Models

- **Forecast, projection, decadal prediction:** a **projection** is a **conditional statement** (if we follow a given emissions pathway, then this will result), typically based on thirty-year averages. A decadal (initialised) forecast starts from observed ocean and atmospheric conditions, and therefore also captures some of the internal variability for the first few years. Neither is a timetable: a decadal prediction also provides a probability range, and its skill varies by variable.
- **Model ensemble, member:** the same model is run multiple times from slightly different initial conditions. Each run is a **member**; the set of all runs constitutes the **model ensemble**. The standard deviation of the members indicates the degree of uncertainty in the result. The average of the model ensemble may be a value that no single run produces – in such cases, the average is misleading.
- **Model range:** the range between the lowest and highest values among the runs of the model ensemble. If, out of the 28 members, the member with the least warming gives +1.5 °C and the most extreme predicts a warming of +4.2 °C for a region, the model range lies between +1.5 and +4.2 °C.

The range reflects the dispersion of the models, not probability; therefore, it does not imply that reality falls within it with any given probability – as the results in Chapter II show, the measurements fall outside the range on several indicators, on the risk side of it.

- **Emissions scenario (RCP): the input for the projections, representing the assumed future radiative forcing trajectory.** The analysis uses two scenarios. RCP4.5 is a **moderate** trajectory – involving substantial but not rapid emissions reductions, with radiative forcing stabilising after the middle of the century. RCP2.6 would represent a strong reduction in emissions, which is not included in the domestic bias-corrected dataset. RCP8.5 is a high-emission scenario, which is not typically expected as a base case today, but is used to define the upper limit of the extreme range. The two are not probability-weighted; therefore, together they provide a range rather than a distribution.
- **Hindcast: the model is run back in time** to a period where we already know what happened. This is the only honest way to assess whether the model’s predictions for the future have any value at all. In this text, the term refers to the initialised, hindcast forecasts of the decadal prediction system. The section of the regional model ensemble run back in time is not referred to as a hindcast, as it is not an initialised forecast but a projection extended into the past.
- **Skill:** measures how much better the model performs than the simple average. Where skill has not been demonstrated, the model values are for information purposes only and do not form a basis for scaling.
- **Downscaling:** the conversion of a coarse-resolution global model field into a finer, national-resolution field. It provides detail, but may also introduce error, as the downscaled field is not a measurement. Downscaling is not a bias correction. The decadal prediction used in the analysis is refined by a neural network trained on observational data; it therefore does not correct the global model’s systematic error, but carries it forward. In retrospective runs, the temperature bias in both models stems predominantly from the global model (II.1).
- **Storyline:** a physically self-consistent but non-probability-weighted scenario – a statement of the ‘it could turn out this way’ type. It should not be interpreted as ‘with this probability’.
- **Breakpoint:** when a time series does not rise gradually but changes level. The planning implication is that a system designed for the long-term average is set to a state that has already passed.

Risk concepts

- **Exposure:** who and what is present where the hazard occurs – a human community, infrastructure or other economic assets, agricultural land, the natural environment.
- **Vulnerability:** the extent to which the exposed system can withstand the impact. Given the same hazard, this determines the magnitude of the damage; therefore, intervention by decision-makers is usually most effective at this stage. This also encompasses the development of adaptive capacity.
- **Temperature change after net-zero emissions (ZEC):** this measures by how much the planet will warm or cool after human carbon dioxide emissions have fallen to net zero. According to the current international assessment, it is roughly zero, with an uncertainty of ± 0.3 °C and low confidence in the direction of the signal (VI.6).
- **Upper oceanic stratification:** the difference in density between the surface water and the layer beneath it. As this increases, the mixing layer becomes thinner, so that the same excess energy causes a greater change in surface temperature (VI.1). This is not the same as a temperature inversion, which is a regional, barrier-layer phenomenon.
- **Planning minimum (minimum rule):** the rule whereby, for those parameters where the model range is verified to remain below the observed values, the value already observed is the minimum permissible value for design purposes, while the lower limit of the model range serves as the lower bound, rather than the conservative or best-case scenario (H.2). This must be verified for each variable.
- **Extreme value range: the edge of the distribution, the range of rare events with large deviations.** Dimensioning relates to this, not to the mean.
- **Evaporative demand:** the atmosphere's capacity to remove moisture, which acts as a boundary condition on the surface. A more precise term would be 'evaporation drive', as the available energy, the vapour pressure deficit and the airflow together draw water away from a surface with an unlimited supply of water. It is not a 'demand' because it cannot be satisfied and persists even over dry soil. Nevertheless, the analysis retains the commonly used term. VPD is its driving force, while reference evaporation (ET₀, mm/day) is its measure. On dry soil, actual evaporation no longer follows this pattern, so it says little about actual water turnover.

- **Vapour pressure deficit (VPD):** a measure of the dryness of the air, indicating how much less moisture it contains than it could hold at a given temperature. Plants perceive this as a compulsion to transpire – at high values, they suffer from water deficiency even when there is water in the soil.
- **Actual evaporation (evapotranspiration):** the water that actually evaporates from the soil and vegetation. It can be measured using the eddy covariance method. Under water-limited conditions, it increases more slowly than the evaporative demand, or does not increase at all.
- **Low flows:** persistently low river levels. This triggers restrictions on navigation, cooling water use and water abstraction.
- **Phenological phase:** a stage in a plant's development (bud burst, flowering, fruit set). The same weather event causes different damage at different phases – therefore, several thresholds are linked to phenological phases rather than calendar dates.
- **Compound event:** a combination of several interrelated hazards or circumstances which, together, cause greater damage than they would individually. None of its components need to be extreme (VIII.3).
- **Ripple effect:** the spread of an impact from one system to another, for example from water scarcity through electricity generation to prices (VIII.3).
- **Polycrisis:** the causal intertwining of crises across multiple systems, in which the crises together cause greater damage than they would individually. A conceptual framework, not a measurement tool (VIII.3).
- **Derailment risk:** the feedback loop whereby climate-related damage diverts attention and resources away from prevention, thereby increasing the subsequent damage (VIII.3).
- **Normalcy bias:** a tendency to underestimate the probability or severity of an expected disruption; the plan does not account for what has not yet happened (VIII.4).
- **Reasonable worst-case scenario:** the worst-case scenario that remains after excluding highly improbable scenarios. Preparedness is scaled to this (VIII.5).
- **Reverse stress test:** the analysis starts from an unacceptable outcome and seeks to identify what combination of factors would lead to it, and how likely that is (VIII.5).
- **Resilience:** the system's ability to absorb disturbances while maintaining its operation. This is distinct from stability, which refers to a rapid return to the original state (VIII.5).

D ANNEX D

Notes and sources

The analysis is based on the cited sources and our own documented calculations. The notes form a single sequence, numbered in the order of their first occurrence in the text; they contain both source references and explanatory comments. If the text subsequently refers to the same source or note, it repeats the number of the earlier note, while cross-references between notes refer to the note number. Where the analysis presents its own calculations, the note specifies the source of the input data and the essence of the calculation. The data on which the calculations are based, the checksums of the source files and the derivations can be found in the project's internal documentation.

1. The grid point data are interpolated values derived from measurements, not individual station measurements. [↔](#)
2. **Damage account:** the cumulative financial cost of damage caused or expected to be caused by climate change – a combined estimate of physical damage, adaptation costs and transition losses. [↔](#)
3. The relationship between the Gulf Stream and the AMOC is regularly conflated in the domestic debate; therefore, the two must be distinguished. The subtropical section of the Gulf Stream is largely wind-driven, forms part of the subtropical gyre, and would persist even if the AMOC – that is, the overturning circulation based on deep-water formation – were to cease. It may weaken, but for a different reason: namely, if the subtropical wind belt weakens. What Western and Northern Europe owe their mild winters to is the north-eastern extension of the current, the North Atlantic Current; however, this belongs to the surface branch of the AMOC, and would therefore weaken in tandem with the AMOC. The analysis therefore concerns the overturn circulation and, through this, the north-eastern branch, not the Gulf Stream as a whole. Source: Wharton, J. H. et al. (2024): *Deeper and stronger North Atlantic Gyre during the Last Glacial Maximum*. *Nature* 632(8023): 95–100. DOI [10.1038/s41586-024-07655-y](https://doi.org/10.1038/s41586-024-07655-y); layman's summary: UCL News, 10 July 2024. [↔](#)
4. Stott, P. A., Lo, Y. T. E., Marsham, J. H., Obura, D., Oliver, T. H., Palmer, M. D., Ranger, N., Sharpe, S., Sutton, R. et al. (2026): *We need a global assessment of avoidable climate-change risks*. Nature 650(8103): 826–828. DOI [10.1038/d41586-026-00544-6](https://doi.org/10.1038/d41586-026-00544-6). The distinction between forecasting and risk assessment is set out on page 3 of the authors' manuscript. A previous, detailed discussion of this point: Sutton, R. T. (2019): *Climate Science Needs to Take Risk Assessment Much More Seriously*. Bulletin of the American Meteorological Society 100(9): 1637–1642. DOI [10.1175/BAMS-D-18-0280.1](https://doi.org/10.1175/BAMS-D-18-0280.1).
5. HM Government / Cabinet Office (2025): *National Risk Register 2025*. 187 pp., published 16 January 2025. The definition of 'reasonable worst-case scenario' is given in Chapters 1 and 2; the distinction between acute and chronic risks and the list of chronic risk topics are provided at the end of Chapter 2.
6. Sharpe, S. (2019): *Telling the boiling frog what he needs to know: why climate change risks should be plotted as probability over time*. Geoscience Communication 2: 95–100. DOI [10.5194/gc-2-95-2019](https://doi.org/10.5194/gc-2-95-2019).
7. Shepherd, T. G. et al. (2018): *Storylines: an alternative approach to representing uncertainty in physical aspects of climate change*. Climatic Change 151(3–4): 555–571. DOI [10.1007/s10584-018-2317-9](https://doi.org/10.1007/s10584-018-2317-9).
8. For a trend to be classified as 'significant' in this analysis, the p-value must fall below an extremely strict threshold adjusted for multiple testing – that is, even a confidence interval of approximately 99.95 per cent, which is considerably wider than 95 per cent, must not encompass zero.

9. HungaroMet Open Data Policy portal (odp.met.hu), a homogenised, interpolated daily database generated at grid points, with a resolution of 0.1°, comprising 1,233 grid points in Hungary, from 1971 onwards. All observed values – temperature, precipitation, derived threshold indices – were derived from this source using our own calculations. The calculation generates the index for each grid point and then averages it nationwide (the reverse order yields a different figure; see Annex B/1.).
10. Kern, A., Dobor, L., Hollós, R., Marjanović, H., Torma, Cs. Zs., Kis, A., Fodor, N., Barcza, Z. (2024): *Seamlessly combined historical and projected daily meteorological datasets for impact studies in Central Europe: The FORESEE v4.0 and the FORESEE-HUN v1.0*. Climate Services 33, 100443. DOI [10.1016/j.cliser.2023.100443](https://doi.org/10.1016/j.cliser.2023.100443). This serves both as the source of the regional model ensemble (14 runs of RCP4.5, 14 runs of RCP8.5, bias-corrected EURO-CORDEX) and as a description of the continuity correction referred to in the preceding paragraph. The model-based values are our own calculations performed on this dataset. We used only the FORESEE-HUN branch: the projection is v1.0 and the observed series v1.4, whose input is the HungaroMet HUCLIM homogenised grid; we did not use the Central European, E-OBS-based FORESEE v4.x branch.
11. HungaroMet: *KLIMADAT geoinformation system – user guide* (gis01.met.hu/klimadat/Felhasznaloi_utmutato.pdf) and the service's ArcGIS interface (gis01.met.hu/server/rest/services/PROD_Klimadat), accessed on 9 and 10 October 2026. The web application and user guide are version 2.0, dated 14 July 2026; the urban layer is described in the 2020–2021 SURFEX reports of the KEHOP-1.1.0–15 project. The projection comprises four runs: ALADIN-Climate and REMO, RCP4.5 and RCP8.5, a 0.1° grid, 30-year sliding windows between 2001 and 2100, with the 1971–2000 period as the reference. According to the guidelines, temperature is corrected using the difference between observed and modelled 30-year daily averages, while precipitation is corrected using the ratio of monthly averages; the indicators are calculated from the corrected daily data. The service reports the minimum, median and maximum values of the four runs for each grid point, while the national values are the grid averages of these (own calculations). ↩
12. Masloumidis, I., Fragkoulidis, G., Kyros, G., Lagouvardos, K. (2026): *Projected Climate Changes in Hungary for 2025–2034 Relative to 1991–2020*. National Observatory of Athens, Institute for Environmental Research and Sustainable Development, Athens. Commissioned dossier; two parts (summary, 17 pp.; complete map dossier, 52 panels). It is based on the WCRP decadal prediction experiment run launched in November 2024 (HadGEM3-GC31-MM and NorCPM1, ten members per model), using the CERRA reanalysis with a 1991–2020 reference period. **The values in Section II.1 do not originate from this dossier, but from downscaled daily fields derived from the same source, processed using our own calculations** – the values published in the dossier combine the twenty members, whereas we present them separately for each model family. The hindcast package (s1980–s2018) is from the same source, for the purpose of assessing skill.
13. Own calculation; the observed series is from the homogenised grid specified in Note 9, the projected series is from the dataset specified in Note 10, and the forcing time series is from the RCP4.5 scenario concentration file and the measured global carbon dioxide time series. Three constraints define the ratio: the ratio is meaningful only within a single forcing estimator (mixing estimators is not permitted, as their accounting boundaries differ); the short 2021–2025 series spans only five years and is subject to internal variability; therefore, the lower value obtained from the long series is more robust; and the response ratio is regional and transient, and thus cannot be directly compared with global climate sensitivity.

14. Own calculation. KLIMADAT: the national grid-cell average of the observed (1996–2025) and projected (2001–2030 ... 2071–2100) layers. FORESEE-HUN: the 28 runs of the bias-corrected v1.0 projection and the v1.4 observed series; the indicators were calculated at each grid point and then averaged across 1,233 grid points. The definitions of the indicators follow the KLIMADAT catalogue: days reaching 30 °C or 35 °C: daily maximum ≥ 30 or ≥ 35 °C; tropical night: daily minimum > 20 °C (the grid-based values in II.1, the table in VII.1 and Annex A use daily minimum ≥ 20 °C; nationally, the two definitions differ by less than 0.06 nights per year); frosty day: daily minimum < 0 °C; day with precipitation: ≥ 1 mm; dry spell: the longest period in the calendar year consisting of days with less than 1 mm of precipitation. The daily mean temperature is the average between 0 and 24 UTC in KLIMADAT, and the average of the daily maximum and minimum in FORESEE-HUN. The lag is the mid-point of the window for the median of the runs at which the measured level is reached (interpolated linearly between the windows), minus the centre of the observation window; as the window lengths of the two datasets differ (30 and 10 years respectively), the lag is provided for information purposes only. The national average of the maximum value at each KLIMADAT grid point is at least as high as the national average of the warmest run; the test therefore also biases the results in favour of the model at this point. The winter FORESEE range is the average of nine winters, as there are no December 2021 data for the first winter of the 2022–2031 window. We report the FORESEE lag for the summer daily maximum as a range, because the window series of the median of the runs flattens out near the measured level, and thus the 0.02 °C uncertainty in the measured value arising from calendar handling shifts the first crossing between 17.8 and 22.3 years. This was revealed by independent verification of the calculations using a different model family.
15. Megyeri-Korotaj, O. A., Bán, B., Suga, R., Allaga-Zsebeházi, G., Szépszó, G. (2023): *Assessment of Climate Indices over the Carpathian Basin Based on ALADIN5.2 and REMO2015 Regional Climate Model Simulations*. Atmosphere 14(3), 448. DOI [10.3390/atmos14030448](https://doi.org/10.3390/atmos14030448). The authors compare the pre-correction model output with the CarpatClim-HU database (1981–2000): “All four simulations slightly underestimated the dry periods of summer and overestimated wet days.” The fact that the correction applied to the service does not adjust the number of wet days follows from the user guide and the aforementioned discrepancy of approximately 27 days.
16. Own calculation. KLIMADAT: the service’s graphical data table (PROD_Klimadat/data_tables/MapServer/7, 539,805 rows, downloaded on 10 October 2026), which reports the measured 30-year average and the minimum, median and maximum values from the four runs for each unit. Units: 20 counties including Budapest, 173 districts, 23 districts of Budapest. The pre-registered statement of the test was recorded prior to the calculation. The daily temperature range is the difference between the average daily maximum and minimum. FORESEE-HUN: annual series of the H.2 test, with a linear trend for 2022–2060 per run, while the observed trend is based on the v1.4 observed series.
17. Kis, A., Pongrácz, R. (2026): *Changes in diurnal temperature range in different climatic regions in Europe between 1971 and 2024*. Atmospheric Research 337, 108938. DOI [10.1016/j.atmosres.2026.108938](https://doi.org/10.1016/j.atmosres.2026.108938). For Hungary, using the HuClim database; the annual average daily temperature range increased from 9.8 °C (1971–1990) to 10.4 °C (2005–2024), a significant increase.
18. Megyeri-Korotaj, O. A., Bán, B., Suga, R., Allaga-Zsebeházi, G., Szépszó, G. (2023), see note 15 (Section 2 and point 3.2.1): ALADIN5.2 reports aerosols as monthly averages over ten-year periods, based on Tegen et al. (1997) for historical data and Szopa et al. (2013) for the scenarios; the aerosol treatment in REMO2015 is simpler, with no annual cycle and no temporal variation (Tanré et al., 1984). The authors explain the more moderate summer warming in the REMO runs, following Boé et al. (2020), by disregarding future aerosol trends.
19. Zelinka, M. D., Myers, T. A., McCoy, D. T., Po-Chedley, S., Caldwell, P. M., Ceppi, P., Klein, S. A., Taylor, K. E. (2020): *Causes of higher climate sensitivity in CMIP6 models*. Geophysical Research Letters 47, e2019GL085782. DOI [10.1029/2019GL085782](https://doi.org/10.1029/2019GL085782).
20. Hausfather, Z., Marvel, K., Schmidt, G. A., Nielsen-Gammon, J. W., Zelinka, M. (2022): *Climate simulations: recognise the ‘hot model’ problem*. Nature 605: 26–29. DOI [10.1038/d41586-022-01192-2](https://doi.org/10.1038/d41586-022-01192-2). The assessed range: IPCC (2021): *Climate Change 2021: The Physical Science Basis. Summary for Policymakers*, Section A.4.4.

21. Boé, J., Somot, S., Corre, L., Nabat, P. (2020): *Large discrepancies in summer climate change over Europe as projected by global and regional climate models: causes and consequences*. Climate Dynamics 54: 2981–3002. DOI [10.1007/s00382-020-05153-1](https://doi.org/10.1007/s00382-020-05153-1).
22. Schumacher, D. L., Singh, J., Hauser, M. et al. (2024): *Exacerbated summer European warming not captured by climate models neglecting long-term aerosol changes*. Communications Earth & Environment 5, 182. DOI [10.1038/s43247-024-01332-8](https://doi.org/10.1038/s43247-024-01332-8).
23. Nordling, K., Fahrenbach, N. L. S., Lipponen, A. et al. (2026): *First crossings of global warming levels in CMIP6 in light of observed 1.5 °C exceedance*. npj Climate and Atmospheric Science 9, 120. DOI [10.1038/s41612-026-01401-z](https://doi.org/10.1038/s41612-026-01401-z). The model with the highest sensitivity under investigation is CanESM5; a well-calibrated example with moderately high sensitivity is ACCESS-ESM1-5; MIROC6, with lower sensitivity, crosses the threshold approximately a decade later.
24. Mann, M. E., Steinman, B. A., Fernandez, A., Christiansen, S. A., Li, X. (2026): *The 2024 global temperature record is consistent with model-predicted warming*. Proceedings of the National Academy of Sciences 123(20), e2600021123. DOI [10.1073/pnas.2600021123](https://doi.org/10.1073/pnas.2600021123).
25. Boardman, P. J. L., Clarke, J., Cox, P. M., Huntingford, C., Jones, C. D., Williamson, M. S. (2026): *Emergent constraints on climate sensitivity and recent record-breaking warm years*. Earth System Dynamics 17, 829. DOI [10.5194/esd-17-829-2026](https://doi.org/10.5194/esd-17-829-2026). · Tokarska, K. B., Stolpe, M. B., Sippel, S., Fischer, E. M., Smith, C. J., Lehner, F., Knutti, R. (2020): *Past warming trend constrains future warming in CMIP6 models*. Science Advances 6, eaaz9549. DOI [10.1126/sciadv.aaz9549](https://doi.org/10.1126/sciadv.aaz9549) – the filtered median is 16 per cent and 14 per cent lower than the raw median for 2050, and 14 per cent and 8 per cent lower for 2090, under the high-emission and mitigation scenarios respectively. · Hausfather, Z., Marvel, K., Schmidt, G. A., Nielsen-Gammon, J. W., Zelinka, M. (2022): *Climate simulations: recognise the ‘hot model’ problem*. Nature 605, 26–29. DOI [10.1038/d41586-022-01192-2](https://doi.org/10.1038/d41586-022-01192-2). ↩
26. Hausfather, Z. (2025): *State of the climate: 2024 sets a new record as the first year above 1.5°C*. Carbon Brief, 10 January 2025. · Hausfather, Z. (2026): *State of the climate: 2025 ranks among the top three hottest years on record as ocean heat surges*. Carbon Brief, 14 January 2026. Both comparisons were made using the SSP2-4.5 ensemble of 37 models and the warming trajectory assessed in the IPCC’s Sixth Assessment Report. The baseline assessment for 2022: Hausfather et al. (2022), see note 20.
27. Hausfather, Z.: *Climate Dashboard – Models* (dashboard.theclimatebrink.com/#models; data: assets/data/models_trends_cmip6.csv), data as at 3 October 2026, downloaded on 10 October 2026. CMIP6, SSP2-4.5, 40 members, unfiltered; median of five observational data sets. The rate measured since 2001 is 0.26 °C, while the model average is 0.28 °C per decade.
28. Hodnebrog, Ø., Myhre, G., Jouan, C., Andrews, T., Forster, P. M. et al. (2024): *Recent reductions in aerosol emissions have increased Earth’s energy imbalance*. Communications Earth & Environment 5, 166. DOI [10.1038/s43247-024-01324-8](https://doi.org/10.1038/s43247-024-01324-8). The cited trend is 0.47 ± 0.17 W/m² per decade, of which the reduction in aerosols accounts for 0.2 ± 0.1 .
29. Bimpiri, K., Hocking, T., Mauritsen, T. (2026): *Climate models with moderate climate sensitivity best simulate the magnitude of Earth’s energy imbalance*. Earth System Dynamics 17, 877–892. DOI [10.5194/esd-17-877-2026](https://doi.org/10.5194/esd-17-877-2026). ↩
30. Met Office: *New flagship climate models – UKESM1 and HadGEM3-GC3.1* (metoffice.gov.uk/research/approach/modelling-systems/new-flagship-climate-models), downloaded on 9 October 2026: equilibrium sensitivity approximately 5.5 °C, transient sensitivity approximately 2.7 °C. The website does not distinguish between resolution variants (the MM version used in the text).
31. Swaminathan, R., Schewe, J., Walton, J., Zimmermann, K., Jones, C., Betts, R. A. et al. (2024): *Regional impacts poorly constrained by climate sensitivity*. Earth’s Future 12, e2024EF004901. DOI [10.1029/2024EF004901](https://doi.org/10.1029/2024EF004901).
32. Duffy, M. L., Simpson, I. R., Medeiros, B. et al. (2026): *Is the high ECS in CESM2 degrading transient climate change projections over the 21st century?* Journal of Advances in Modelling Earth Systems 18(1), e2025MS004967. DOI [10.1029/2025MS004967](https://doi.org/10.1029/2025MS004967).

33. Dittus, A. J., Hawkins, E., Wilcox, L. J., Sutton, R., Smith, C. J., Andrews, M. B., Forster, P. M. (2020): *Sensitivity of historical climate simulations to uncertain aerosol forcing*. Geophysical Research Letters 47(13), e2019GL085806. DOI [10.1029/2019GL085806](https://doi.org/10.1029/2019GL085806). The study was carried out using the HadGEM3-GC3.1 large ensemble across a wide range of present-day aerosol forcing; for aerosol forcing stronger than -1 W/m^2 , the mid-century cooling is also more pronounced than that observed.
34. Boé, J., Terray, L., Moine, M.-P. et al. (2020): *Past long-term summer warming over western Europe in new-generation climate models: role of large-scale atmospheric circulation*. Environmental Research Letters 15, 084038. DOI [10.1088/1748-9326/ab8a89](https://doi.org/10.1088/1748-9326/ab8a89).
35. Own calculations. Model data source: the Climate Impact Lab's GDPCIR database, ssp245 scenario, 23 global models, daily maximum and minimum temperatures, 0.25° grid, with changes relative to the models' own 1995–2014 period (Gergel, D. R., Malevich, S. B., McCusker, K. E., Tenezakis, E., Delgado, M. T., Fish, M. A., Kopp, R. E. (2024): *Global Downscaled Projections for Climate Impacts Research (GDPCIR): preserving quantile trends for modelling future climate impacts*. Geoscientific Model Development 17, 191–227. DOI [10.5194/gmd-17-191-2024](https://doi.org/10.5194/gmd-17-191-2024).) Observations: HungaroMet homogenised daily grid (Open Data Policy portal), 1,233 grid points, national average; model cells were weighted by the number of observation grid points falling within them. Between 1995 and 2014, the measured summer daily maximum was 0.5°C warmer than the median of the models. The calculation was verified by an independent re-analysis of raw data. On days when the temperature reached 30°C , the result of the comparison at this level depends on a specific aspect of the weighting. For both the summer daily maximum and days reaching 30°C , the model that matches the observed change is the standard-resolution (LL) version of HadGEM3-GC3.1, run according to the scenario. The model has several resolution variants (Roberts, M. J. et al. (2019): *Description of the resolution hierarchy of the global coupled HadGEM3-GC3.1 model as used in CMIP6 HighResMIP experiments*. Geoscientific Model Development 12, 4999–5028. DOI [10.5194/gmd-12-4999-2019](https://doi.org/10.5194/gmd-12-4999-2019).). The decadal prediction is produced using the medium-resolution (MM) version of this same model, initialised from observed conditions. Its reliability is determined by retrospective validation (H.3); no conclusions regarding this can be drawn from the agreement observed here. High climate sensitivity alone does not explain the agreement, as the model with the highest sensitivity in the ensemble (CanESM5) remains below the measured change, and sensitivity is weakly correlated with summer warming in Hungary across the models (rank correlation 0.28, 23 models).
36. Rybka, H., Leps, N., Mannig, B., Paxian, A., Dalelane, C., Winderlich, K., Steger, C., Früh, B. (2026): *Benchmarking Across Scales: Evaluating EURO-CORDEX CMIP6 Regional Climate Models over Germany*. EMS Annual Meeting 2026, EMS2026–476 (conference abstract).
37. Dunne, J. P., Hewitt, H. T., Arblaster, J. M., Bonou, F., Boucher, O. et al. (2025): *An evolving Coupled Model Intercomparison Project phase 7 (CMIP7) and Fast Track in support of future climate assessment*. Geoscientific Model Development 18, 6671–6700. DOI [10.5194/gmd-18-6671-2025](https://doi.org/10.5194/gmd-18-6671-2025).
38. van Vuuren, D. P., O'Neill, B. C., Tebaldi, C., Sanderson, B. M., Chini, L. P. et al. (2026): *The Scenario Model Intercomparison Project for CMIP7 (ScenarioMIP-CMIP7)*. Geoscientific Model Development 19, 2627–2656. DOI [10.5194/gmd-19-2627-2026](https://doi.org/10.5194/gmd-19-2627-2026). According to the article, the timetable for the scenarios is as follows: runs of the Earth system models start in spring 2026, and those for additional scenarios in June 2026.
39. This is natural, as there are physical and meteorological reasons for the differing predictability of temperature and precipitation, and this discrepancy is also observed in other model systems.
40. Yuan, X., Wang, L., Wu, P., Ji, P., Sheffield, J., Zhang, M. (2019): *Anthropogenic shift towards higher risk of flash drought over China*. Nature Communications 10, 4661. DOI [10.1038/s41467-019-12692-7](https://doi.org/10.1038/s41467-019-12692-7). Optimal fingerprint attribution, 1961–2005; the study is based on Chinese data and the authors' own definition of flash drought, so the proportion cannot be directly transferred to other definitions.

41. Yuan, X., Wang, Y., Ji, P., Wu, P., Sheffield, J., Otkin, J. A. (2023): *A global transition to flash droughts under climate change*. Science 380, 187–191. DOI [10.1126/science.abn6301](https://doi.org/10.1126/science.abn6301). The study covers a period of sixty-four years. The authors attribute this acceleration to evaporation and precipitation anomalies caused by human-induced climate change. We have classified Central Europe in the exposed class based on the region's moisture class; the paper does not make this claim.
42. IPCC (2021): *Summary for Policymakers*. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, 3–32. DOI [10.1017/9781009157896.001](https://doi.org/10.1017/9781009157896.001); IPCC (2022): *Summary for Policymakers*. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report. Cambridge University Press, 3–33. DOI [10.1017/9781009325844.001](https://doi.org/10.1017/9781009325844.001). The entries in Table A are qualitative statements from the summaries; the quantitative AR6 values can be found in Table VI.6 and in the referenced sections. The classification is based on our own judgement. ↩
43. The rationale for the model selection is based on our own calculations: the summer maximum temperature of NorCPM1 in its own 1991–2020 hindcast climatology is 4.3 °C below the observed value, the spatial standard deviation of daily maximums is half as large, and the 35 °C threshold is reached 0.05 times per year during the reference period. The system therefore does not ‘provide a cooler forecast’, but rather does not register on the threshold indicator at all. The ranges of the ten members from each of the two systems do not overlap for the annual mean temperature (NorCPM1 +0.56...+1.19 °C, HadGEM3 +1.23...+2.04 °C); therefore, the combined average is a value that no single run produces. The full two-model breakdown can be found in the project's internal documentation; the analysis uses HadGEM3 as the working model. ↩
44. Own calculation, comparing three versions of the same run: the NOA downscaled daily field, the raw global model field (CMIP6 DCP, dcppA-hindcast, downloaded from the international archive on 29 September 2026) and the HungaroMet homogenised daily grid. All three were projected onto the 1,230 points of the national grid, using the 39 initialisations of the r1 member (1980–2018); forecast years 2–10, target years 1991–2020, with 270 sample years per model. The total bias is broken down into the global model bias and the contribution from downscaling. NorCPM1, summer mean temperature: –2.96 °C, of which 0.00 °C is attributable to downscaling; extremely hot days: 0.05 instead of the measured 2.82; the contribution from downscaling is +0.01 days. HadGEM3, extremely hot days: 8.2 instead of the measured 2.8; of the +5.35-day excess, the contribution from downscaling is +0.73 days. The 8.2 value and the 8.6 value in the main text are derived from different samples (forecast years 2–10 and 1–10, respectively). The result was independently verified by recalculating it from the raw data using its own code. ↩
45. Own calculation based on the daily fields of the downscaled decadal prediction (National Observatory of Athens; HadGEM3-GC31-MM and NorCPM1, November 2024 run, ten runs per model), using a Hungary mask. The deviation is measured against the model's own 1991–2020 climatology, sorted by forecast month, based on the average of daily maximum and minimum temperatures; in the HadGEM3 360-day calendar, the months are equally weighted, and the number of extremely hot days is normalised by a factor of 365/360. The observed data set was derived in the same way. Prior to the calculation, it was noted that the first year could only be reported in terms of its rank amongst the members. The calculation was repeated by an independent reviewer. ↩
46. Met Office Hadley Centre and the University of East Anglia Climatic Research Unit: HadCRUT5 global surface temperature database, analysis version 5.1.0.0 (metoffice.gov.uk/hadobs/hadcrut5): global (NH+SH)/2 annual anomaly series from 1850, relative to the 1961–1990 baseline. Own calculation: the difference between the averages of the 1971–1980 and 2021–2025 time windows. ↩

47. Cornes, R. C., van der Schrier, G., van den Besselaar, E. J. M., Jones, P. D. (2018): *An Ensemble Version of the E-OBS Temperature and Precipitation Data Sets*. Journal of Geophysical Research: Atmospheres 123, 9391–9409. DOI [10.1029/2017JD028200](https://doi.org/10.1029/2017JD028200). Version used: E-OBS v33.0e, ensemble mean version, 0.25°, downloaded from the Copernicus Climate Data Store on 27 September 2026. Own calculation: each grid point in Hungary was assigned the value of the nearest valid E-OBS cell, with the threshold index calculated for each grid point. The matching criteria set before the calculation (annual correlation of at least 0.9; the same sign of change; a ratio of increments between 1/1.5 and 1.5) were all met. The calculation was replicated by an independent review. In this analysis E-OBS serves only as a check; no finding rests on it. ↩
48. Ridal, M., Bazile, E., Le Moigne, P., Randriamampianina, R., Schimanke, S. et al. (2024): *CERRA, the Copernicus European Regional Reanalysis system*. Quarterly Journal of the Royal Meteorological Society 150(763), 3385–3411. DOI [10.1002/qj.4764](https://doi.org/10.1002/qj.4764). Dataset: Copernicus Climate Change Service: *CERRA sub-daily regional reanalysis data for Europe at single levels from 1984 to the present*. Climate Data Store, DOI [10.24381/cds.622a565a](https://doi.org/10.24381/cds.622a565a); 2 m temperature, eight analysis times per day, 2015–2025, downloaded on 27–28 September 2026. Production ran until June 2021 under an earlier contract and, from July 2021, runs under a new contract on a system transferred to the ECMWF’s computer in Bologna; the service provider intends the continuation to be consistent with the previous data set (Copernicus Climate Change Service: *Regional climate reanalysis timely updates*, climate.copernicus.eu). Own calculation: each domestic grid point was assigned the nearest reanalysis cell. All the matching criteria set prior to the calculation (annual deviation within ± 0.5 °C, daily correlation of at least 0.98, and a negative deviation for the summer daily maximum) were met. The examination of the 2021 shift is retrospective, with no pre-specified test. The calculation was repeated by an independent review. ↩
49. Own calculation based on the homogenised daily precipitation grid specified in Note 9, 1,233 grid points, 1971–2025. The definition of a dry day is 1.0 mm per day, in accordance with the conventions of the International Climate Index Set (ETCCDI). The longest dry period is the annual maximum calculated per grid point, then averaged nationally – the value calculated in reverse order (first national average precipitation, then thresholding) represents a different quantity, and combining the two constitutes a separate error class. The period truncated to the calendar year is 27.4 days, while the period spanning the calendar year boundary is 28.3 days. ↩
50. Kis, A., Pongrácz, R. (2025): *Scenario-Dependent Future Trends of Consecutive Dry Days From July to September: A Case Study for Hungary*. International Journal of Climatology 45(10), e8903. DOI [10.1002/joc.8903](https://doi.org/10.1002/joc.8903). The study uses a 3 mm threshold, a July–September window, and the HuClim 1971–2023 dataset – the threshold, the window and the dataset all differ from our own calculation above; therefore, the two sets of values cannot be directly compared, and the agreement holds at the level of conclusion. The projection section of the study reports the average of six regional model simulations (RCP2.6, RCP4.5, RCP8.5), with bias correction applied to the calculated index; the area shares with 2–5 occurrences in 20 years are taken from Section 3.2 of the article; their assignment to the scenarios is our interpretation based on the context. ↩
51. HungaroMet KLIMADAT climate geoinformation system (klimadat.met.hu), observed and projected layers. The threshold convention of 1.0 mm per day, published in the configuration service behind the interface, is identical to that of our own calculations; therefore, the cross-check is valid. The projected layer is based on four runs, with a 1971–2000 reference period; the correction procedure and the comparison of the number of rainy days are described at the end of section H.2. The measured and projected values are taken from the service’s own layers, as national grid averages, based on our own calculations, retrieved on 9 October 2026. ↩
52. If this window is cited anywhere, the source and year must be stated alongside it. ↩
53. A decadal prediction product from the National Observatory of Athens (NOA). ↩

54. HungaroMet Nonprofit Zrt. (2026): assessment of temperature and precipitation conditions in the summer of 2026, published on 7 September 2026, based on preliminary data; cited unanimously by the press (Portfolio, Telex, Infostart) on 7–8 September 2026. The drought area percentages (98 per cent, 47.1 per cent) are taken from the data provider’s August 2026 announcements, as quoted in the press; they are therefore a secondary source. **Correction:** earlier editions of the analysis presented our own series aggregated from 266 stations (1 June – 27 August 2026: 66.7 mm); this has been replaced by the official, complete summer figure. ↩
55. Own calculation. The homogenised daily precipitation series from HungaroMet’s open data portal for ten stations (Budapest, Debrecen, Keszthely, Miskolc, Nyíregyháza, Pécs, Sopron, Szeged, Szombathely, Túrkeve), 1901–2025, supplemented by the 2026 daily observations from the same stations, subject to preliminary quality control (up to 30 September 2026). Dry day: daily precipitation < 1.0 mm; the longest period within the given window, per station, followed by the average across the ten stations. A year is excluded if more than 10 per cent of the days in the window are missing at any station (in the April–September window, 115 years remain out of 1901–2025; the 1991–2020 average is based on 28 years, with 2013 and 2014 excluded). The homogenised series for 2021–2025 matches the station’s raw series day-for-day at nine stations; in Pécs, there is a seven-day discrepancy in July 2021, so the 2026 value is based on the same basis. The 2026 figure is provisional. The average for ten stations does not match the grid-based national average; the two values cannot be interconverted. ↩
56. Own calculation. The primary data source for the four VPD indicators is the observed branch of FORESEE-HUN v1.4 (its input is the HungaroMet HUCCLIM homogenised grid, Note 10), which approximates air humidity using the daily minimum temperature. The verification calculation was carried out using the measured relative humidity and temperature grids from the official open data portal. The direction of the approximation is known and works against the result, as it underestimates the vapour pressure deficit under dry conditions; thus, the reported increase is a lower estimate. The rise in the diurnal temperature range and the rise in the vapour pressure deficit are not two independent pieces of evidence, but two perspectives on a single physical phenomenon. The ET₀ values are based on the same grid, calculated according to the FAO-56 Penman–Monteith method. The projection branch is produced using the same method (MT-CLIM): it estimates the daytime vapour pressure deficit from bias-corrected daily minimum and maximum temperatures and precipitation for the entire 1950–2100 period; it does not use moisture and radiation data from regional models, nor does it apply an aridity correction (Kern et al. 2024, Climate Services 33, 100443, methodology section). The bias correction applies to temperature and precipitation, but not to air humidity. On the same grid and using the same definition of daily averages, the summer vapour pressure deficit trend calculated from measured air humidity is +61.9, while that calculated using the minimum temperature estimate is +41.7 Pa/decade. The difference is concentrated in critical situations. During heatwaves lasting at least three days with temperatures above 30 °C, over parched soil, the measured water vapour pressure shows no detectable trend between 1971 and 2025, and the estimate accounts for 43–54 per cent of the increase in the vapour pressure deficit between 1971–1990 and 2011–2025, depending on the definition of soil condition and heatwave; the number of such days has increased from three per year per grid point to between ten and thirteen, with the highest number recorded in 2022. The parched antecedent condition is a state estimated from precipitation totals or from a simple soil water balance, not a soil moisture measurement. Based on raw daily data from ten continuously operating synoptic stations (preliminary data, up to 28 August 2026), the measured vapour pressure deficit on such days averaged 1,950 Pa in the summer of 2026, compared with an estimated 1,360 Pa; in 2022, the figures were 1,670 Pa and 1,260 Pa respectively. ↩
57. Dunkl, I., Bastos, A., Sippel, S. (2026): *European summer drying largely driven by atmospheric circulation changes since the 1980s*. Nature Geoscience 19, 914–921. DOI [10.1038/s41561-026-02050-w](https://doi.org/10.1038/s41561-026-02050-w). The decomposition was carried out using a single model (CESM2), and the method excludes the influence of thermodynamics on the flow; the study area covers the mid-latitudes of Europe and is not Hungary-specific. The 10 cm soil moisture variable used in the study is a model estimate, not a measurement. ↩

58. Simon, Cs., Kis, A., Torma, Cs. Zs. (2025): *Evaluation of bias-corrected EURO-CORDEX databases and projected precipitation changes in Hungary*. Science of the Total Environment. DOI [10.1016/j.scitotenv.2025.180451](https://doi.org/10.1016/j.scitotenv.2025.180451). ↩
59. Simpson, I. R. et al. (2024): *Observed humidity trends in dry regions contradict climate models*. PNAS. DOI [10.1073/pnas.2302480120](https://doi.org/10.1073/pnas.2302480120). · Markonis, Y. et al. (2021): *The rise of compound warm-season droughts in Europe*. Science Advances. DOI [10.1126/sciadv.abb9668](https://doi.org/10.1126/sciadv.abb9668). ↩
60. Treydte, K. et al. (2024): *Recent human-induced atmospheric drying across Europe unprecedented in the last 400 years*. Nature Geoscience 17, 58–65. DOI [10.1038/s41561-023-01335-8](https://doi.org/10.1038/s41561-023-01335-8). A network of $\delta^{18}\text{O}$ measurements from oak and pine at 45 sites; formal attribution was carried out for four regions, one of which is the Central and Eastern European cluster. ↩
61. Ionita, M., Nagavciuc, V. (2021): *Changes in drought features at the European level over the last 120 years*. Natural Hazards and Earth System Sciences 21, 1685–1701. DOI [10.5194/nhess-21-1685-2021](https://doi.org/10.5194/nhess-21-1685-2021). Three indices (SPI, SPEI, scPDSI), 1902–2019; the drying trend is indicated by the SPEI and scPDSI. Potential evaporation in the article is calculated using the Penman–Monteith method (based on CRU TS v4.04); it is therefore methodologically related to the vapour pressure deficit layer discussed in this chapter and does not constitute independent evidence. The argument of the analysis is based on the measured vapour pressure deficit. ↩
62. Own calculation based on the homogenised daily temperature grid specified in Note 9, in the copy held in the observed branch of FORESEE-HUN v1.4; an approximate indicator of budburst based on heat sum (cumulative heat sum from 1 February, based on 5 °C, with thresholds of 100/150/200 °C-days). The model-based comparison covers the fourteen members of the dataset specified in Note 10, under the moderate emissions scenario. The aggregation sensitivity of the frost-risk window indicator is set out in the project’s internal documentation, while the results of multiple testing are provided in point 7 of Annex B. ↩
63. Szécsény, 30 June 2026, 42.0 °C, during the heatwave that began on 20 June; the previous national record high was 41.9 °C (Kiskunhalas, 20 July 2007). Source: HungaroMet’s report of 30 June 2026, confirmed by the service’s summer assessment of 7 September 2026. The figure of +40.9 °C appearing in previous editions is therefore obsolete. The minimum of –18.3 °C is taken from the official measurement series. ↩
64. Own calculation based on the homogenised daily precipitation grid specified in Note 9, in the copy held in the observed branch of FORESEE-HUN v1.4 (whose calendar adds the 31 December value to 30 December in leap years); the indices are calculated for each grid point, with the 95th percentile threshold determined for each grid point, based on wet days from the 1971–2000 reference period. The internal variation on the model side is based on a comparison of the fourteen members of the dataset specified in Note 10 for the periods 2022–2050 and 2071–2100 – the bias is eliminated because the same member appears in both time windows. ↩
65. The temperature dependence of water-holding capacity (Clausius–Clapeyron relationship) is presented here as a **mechanistic reference, not a numerical forecast**. Three limitations: the models underestimate the observed scaling; over subtropical land, the atmospheric circulation component subtracts from the thermodynamic expectation; and in drying regions, near-surface humidity does not increase in accordance with the relationship, so the vapour pressure deficit there rises faster than expected (see the first item in the international reference in Section II.2). ↩
66. Note on the choice of indicators: when calculated using the national average series, these same indicator names yield different figures – the daily maximum for 1971–2000 is 19.8 mm there, instead of the 33.5 mm given above – and the order of the p-values is also reversed. We use only the grid-point version; the average series index may only be cited with a separate designation. ↩
67. Water Management Authority (data.vizugy.hu), water level time series: Budapest (Danube), Szolnok and Vásárosnamény (Tisza), June 2013 and September 2024; own query, retrieved on 26 August 2026. The 2013 value is also the highest water level ever recorded at the Budapest gauging station. ↩

68. Vautard, R., Cattiaux, J., Hap  , T., Singh, J., Bonnet, R., Cassou, C., Coumou, D., D’Andrea, F., Faranda, D., Fischer, E., Ribes, A., Sippel, S., Yiou, P. (2023): *Heat extremes in Western Europe increasing faster than simulated due to atmospheric circulation trends*. Nature Communications 14, 6803. DOI [10.1038/s41467-023-42143-3](https://doi.org/10.1038/s41467-023-42143-3). The 170 simulations comprise 32 models, including three large model ensembles. [↵](#)
69. Rousi, E., Kornhuber, K., Beobide-Arsuaga, G., Luo, F., Coumou, D. (2022): *Accelerated western European heatwave trends linked to more persistent double jets over Eurasia*. *Nature Communications* 13, 3851. DOI [10.1038/s41467-022-31432-y](https://doi.org/10.1038/s41467-022-31432-y); authors’ correction: 14, 4560 (2023). The European heat-wave trend is three to four times faster than in other northern mid-latitude regions; dual jet stream configurations account for up to 35 per cent of temperature variability in Western Europe, while their increased persistence accounts for almost the entirety of the accelerated trend in Western Europe and approximately 30 per cent of that in the wider European region. [↵](#)
70. F  hrer E. (2017): *A new delineation of forest climate classes based on ecophysiological criteria*. Erd  szeti Lapok 152(6): 173–174. The class boundaries of the Forest Drought Index (FAI) are as follows: beech forests below 4.75; hornbeam-oak forests between 4.75 and 6.00; sessile oak and Turkey oak forests between 6.00 and 7.25; and forest steppe above this value. The author assessed the usefulness of the index using data from 94 domestic meteorological stations; the area proportions apply to the entire territory of the country, though the article does not specify the database on which they are based. [↵](#)
71. National Adaptation Geoinformation System (NAT  r), ‘Changes in forestry climate classes between 1961–1990 and 1991–2010 based on the CARPATCLIM-HU database’ layer; retrieved from the HungaroMet map service on 21 September 2026. The cell counts are our own aggregation of the layer’s 1,104 grid cells. The layer description does not specify the calculation method; the classes correspond to the four classes defined by the forestry aridity index, so methodological equivalence is likely but not verified. [↵](#)
72. Own calculation; the precipitation data are from the grid specified in Note 9, covering the Danube–Tisza interfluvial sand ridge box (lat. 46.1–47.2 / long. 19.0–20.1, 121 grid points); the groundwater data are from 57 wells in the official monitoring well network for which January and August values are available for every year between 2001 and 2026. Three constraints: the August → January window excludes the late-winter thaw; twenty-four winters; and the box-averaged precipitation is assigned to the well panel. The correlation is of moderate strength (Pearson $r = 0.53$), with the net zero replenishment arising from the intercept of the fit. [↵](#)
73. Own calculation based on the snow depth and snow-water equivalent codes from the hydrometeorological master database of the National Water Authority, using a fixed group of stations covering at least twenty-three of the twenty-four winters (17 and 14 stations respectively). Literature reference for the prominent role of winter recharge: Jasechko, S. et al. (2014): The pronounced seasonality of global groundwater recharge. Water Resources Research 50(11): 8845–8867. DOI [10.1002/2014WR015809](https://doi.org/10.1002/2014WR015809). On the opposite effect (frozen soil, midwinter thaw): Hyman-Rabeller, K., Loheide, S. P. (2023): Drivers of Variation in Winter and Spring Groundwater Recharge: Impacts of Midwinter Melt Events and Subsequent Freezeback. Water Resources Research 59(1), e2022WR032733. DOI [10.1029/2022WR032733](https://doi.org/10.1029/2022WR032733). [↵](#)

74. Own calculations based on official standard well series, across six regional well groups. The 118 locations in the groups comprise **111 individual wells** (seven wells lie on the boundary between two grids) – the ‘118/118 unidirectional’ figure therefore must not be cited; the correct figure is 111/111. The background to the coverage correction is an internal analysis dated 30 August 2026, which established that the most severe decline is not concentrated in the Homokhátság region; the layer underwent an independent audit on 31 August 2026, resulting in four cell corrections. · The source of the national overview and the comparison of cyclical patterns is the Water Management Authority’s public data portal (data.vizugy.hu): the complete groundwater well master data (2,030 wells, of which 2,003 are operational) and the groundwater level time series for the wells from 1960 to 2026, retrieved on 12 October 2026 and aggregated to monthly medians. Own calculations: Theil–Sen slope for each well based on August levels from 2001 to 2026 (at least twenty-two years, with the 2026 value mandatory); comparison of cyclical patterns across four thirteen-year windows (1975–1987, 1988–2000, 2001–2013, 2014–2026), using the highest annual average level per window (annual average calculated from at least eight monthly values, with at least nine years per window). The 25 cm deviation threshold is arbitrary; between 10 and 50 cm in the 2014–2026 period, 60–96 per cent of the wells east of the Danube remain below the previous peak, and no more than 1 per cent rise above it. The representative wells were selected according to a rule established for each management district: from among the wells with a complete 52-year series, the one whose shortfall for 2014–2026 is closest to the management district’s median. We do not claim statistical significance; we report numbers and medians. ↩
75. Save, H., Bettadpur, S., Tapley, B. D. (2016): *High-resolution CSR GRACE RL05 mascons*. Journal of Geophysical Research: Solid Earth 121, 7547–7569. DOI [10.1002/2016JB013007](https://doi.org/10.1002/2016JB013007); the version used is the CSR GRACE/GRACE-FO RL06.3 mascon solution. · Copernicus Climate Change Service (C3S): satellite gravimetry-derived terrestrial water storage anomalies, v1.0, April 2002 – September 2025 (Climate Data Store, satellite-terrestrial-water-storage), downloaded on 27 September 2026. Own calculation: common 2004–2009 baseline, with the monthly seasonal cycle subtracted, annual average calculated from at least nine valid months (2002, 2015, 2017 and 2018 are therefore excluded); breakpoint test using the Pettitt test, four series, with Bonferroni correction ($p = 0.004$ – 0.005). The calculation was replicated by an independent review. ↩
76. Water Management Service (National Water Management Directorate-General), hydrological data provision (data.vizugy.hu): daily discharge and water level, 1 January 2000 – 27 September 2026, seven gauging stations: Gyula, Békés, Körösszakál, Gyoma, Kunszentmárton, Berettyóújfalu, Makó; retrieved on 28 September 2026. Own calculations: annual average of daily values for June–September, with a minimum coverage of 100 days. The 2026 discharge data for Berettyóújfalu is missing, so the ranking is based on six gauging stations. The lowest recorded water level is the value from the water management master data. At Gyoma, the daily water flow is negative on certain days (backflow at the weir). No trend estimate has been made. The data for 2026 covers the period up to 27 September. ↩
77. Groundwater well data from the Water Management Authority (data.vizugy.hu), monthly averages for January and August, 2001–2026, linear trend per well. The 21 wells in the Körös–Sárrét region were selected from the comparison of the six landscape units (wells measured in both months every year). The 19 wells in Zala and the 25 in Zala–Vas are taken from the complete register of water management wells, with no more than two missing monthly values; in Zala, only four wells meet the stricter selection criteria for the six regions, and these show the same trend (one is sinking, the median is -2.9 cm per decade). The rise in water levels at urban wells (Zalaegerszeg, Nagykanizsa) may also reflect a reduction in water abstraction; we do not make any causal claims. ↩
78. KSH STADAT Tables 19.1.2.4. (wheat, including durum wheat and spelt) and 19.1.2.5. (maize), broken down by county and region, average yield, 2000–2025, updated 30 June 2026. From 2020 onwards, the KSH classifies regional data according to the county in which the land is situated, whereas previously it was based on the farmer’s registered office. The difference observed from 2021 onwards is linked to dry years and virtually disappears by 2023; it is therefore unlikely to be caused by the methodological change. County-level data for 2026 are not yet available. ↩

79. Own calculation based on the confined groundwater level measurement codes from the official network of monitoring wells, using a national group of 102 wells covering all twenty-six years. The alignment of the looser group of 137 wells is a coverage artefact – the missing years fall at the beginning of the period – and therefore cannot be cited. ↩
80. Own calculations based on the official hydrographic master database: the shift in the water level–discharge correlation derived from pairs with matching timestamps, by band, for the windows calculated up to 2008 and from 2019 onwards; flood alert levels from the official Level I–III fields of the same master database (149–151 out of 1,193 stations were recorded; in seven of the eight gauges examined). This official field has superseded our own previous approximate threshold calculation. ↩
81. Kew, S., Zachariah, M., Schumacher, D. L., Lakatos, M., Kovács, A., Erdődiné Molnár, Zs., Cheval, S., Dumitrescu, A., Otto, F. et al. (2026): *Increasingly hot Europe faces more severe droughts*. World Weather Attribution No. 87. DOI [10.25560/131401](https://doi.org/10.25560/131401). With three co-authors from HungaroMet. Methodological note: the attribution estimate is based on a measure of evaporative demand; therefore, **it is methodologically related to the vapour pressure deficit layer in Section II.2** and does not constitute independent evidence. ↩
82. Taylor, R. G., Todd, M. C., Kongola, L., Maurice, L., Nahozya, E., Sanga, H., MacDonald, A. M. (2013): *Evidence of the dependence of groundwater resources on extreme rainfall in East Africa*. *Nature Climate Change* 3, 374–378. DOI [10.1038/nclimate1731](https://doi.org/10.1038/nclimate1731). A semi-arid, sandy Tanzanian catchment: the vast majority of groundwater recharge originates from extreme rainfall during the wettest seasons. ↩
83. National Adaptation Geoinformation System (NATÉR), ‘Sensitivity of drinking water resources’ layer group; retrieved from the HungaroMet map service on 21 September 2026; figures compiled by the authors. Methodology: Rotárné Szalkai Á., Homolya E., Selmeczi P. (2015): *The impact of climate change on drinking water resources*. Research report, Hungarian Geological and Geophysical Institute, 15 December 2015; Rotárné Szalkai Á., Fejes L., Selmeczi P. (2020): *Climate vulnerability of drinking water supply in settlements: a case study of key water utility providers in Hungary*. Hungarian Mining and Geological Service. The 2015 report has been processed at the level of the title and table of contents, while the full text of the 2020 report has been processed (published online, retrieved on 21 September 2026); the figures are taken from the map layer, and the text indicates where the report’s table differs from this. ↩
84. NATÉR, ‘30-year average of infiltration values calculated from the CARPATCLIM-HU database, 1975–2004’ layer; retrieved from the HungaroMet map service on 21 September 2026. The area proportion is our own calculation based on the layer’s 15,161 polygons, using a spherical approximation (total area 90,647 km²). ↩
85. NATÉR, ‘Classified catchment areas’ layer; retrieved from the HungaroMet map service on 21 September 2026, own compilation. On the methodology: Turczi G., Homolya E., Mattányi Zs. (2016): *Flash flood vulnerability in Hungary’s mountainous and hilly regions*. In: the system’s 2016 collection of studies, Hungarian Geological and Geophysical Institute; identified by the title of the study, full text not read. ↩
86. Páldy A., Bobvos J., Rudnai T. (2024): *Review and development of the heatwave warning system*. Health Sciences 67(1): 36–52. DOI [10.29179/EgTud.2024.1.36-52](https://doi.org/10.29179/EgTud.2024.1.36-52). Open-access, peer-reviewed article; the authors are staff members of the National Centre for Public Health and Pharmacy. **Source criticism:** this figure does not originate from institutional data reporting but from a peer-reviewed article – the attribution ‘NNGYK data’, which has been circulated in the press, is inaccurate. Regarding the spatial pattern and the study forming the basis of the national adaptation system: Bobvos J., Málnási T., Rudnai T., Cserbik D., Páldy A. (2017): *The effect of climate change on heat-related excess mortality in Hungary at different area levels*. Időjárás 121(1): 43–62. ↩

87. The finding regarding the heatwave at the end of June 2026 is derived from excess mortality calculations based on official mortality data; **the data are provisional, as indicated by the data provider, and the acquisition of an updated time series from the primary source was still in progress at the time of this edition's finalisation** (see Annex E). We therefore present a qualitative description rather than a claim: no significant excess mortality was detectable from the provisional data; however, this does not prove the absence of an excess. Comparative estimates from Western Europe relating to this event are not included in this edition, as they employ different methodologies and we have not verified their primary sources. ↩
88. Huber, V., Breitner-Busch, S., Feldbusch, H., Frieler, K., He, C., Matthies-Wiesler, F., Mengel, M., Zhang, S., Peters, A., Schneider, A. (2025): *Improvements in life expectancy mask rising trends in heat-related excess mortality attributable to climate change*. Nature Communications 16, 11632. DOI [10.1038/s41467-025-66681-0](https://doi.org/10.1038/s41467-025-66681-0). ↩
89. Eurostat: *Deaths by week and sex* (demo_r_mwk_ts), downloaded on 27 September 2026; weeks in 2025–2026 are provisionally marked. Own calculation: the baseline is the median for the given calendar week across the previous five years, excluding pandemic years; weekly heat load is derived from the national daily maximum of the homogenised national grid. The nominal p-value of the correlation is very small, but consecutive weeks within a single summer are not independent; therefore, the correlation coefficient is robust, while the p-value overstates the significance. The total summer excess is sensitive to the choice of baseline and was therefore not used as a heat indicator. The annual sum of hot-day weeks is a retrospective, exploratory addition not specified prior to the calculation; the weekly relationship is the pre-specified result. The calculation was replicated by an independent review. ↩
90. Janoš, T., Quijal-Zamorano, M., Shartova, N., Gallo, E., Méndez Turrubiates, R. F., Beltrán Barrón, N. D., Peyrusse, F. et al. (2025): *Heat-related mortality in Europe during 2024 and health emergency forecasting to reduce preventable deaths*. *Nature Medicine* 31: 4065–4074. DOI [10.1038/s41591-025-03954-7](https://doi.org/10.1038/s41591-025-03954-7). National figures: Table 1; age-group figures: supplementary tables (Extended Data 3–4). The estimate reflects excess mortality attributed to heat, not observed excess mortality; the authors' correction in November 2025 does not affect the figures. ↩
91. Central Statistical Office: *Demographic Yearbook*, 2011–2024, Table 6.2.6 (Number of deaths per day); HungaroMet homogenised daily mean temperature grid, simple national average of 1,233 grid points. Own calculation: quasi-Poisson regression with a distributed-lag non-linear term (Gasparrini, A., Armstrong, B., Kenward, M. G. (2010): *Distributed lag non-linear models*. Statistics in Medicine 29(21): 2224–2234. DOI [10.1002/sim.3940](https://doi.org/10.1002/sim.3940)); lag 0–21 days; time trend with 7 degrees of freedom per year; control for day of the week and public holidays; 2011–2019 and 2023–2024, 3,997 days. The temperature associated with minimum mortality is 21.9 °C. At the 99th percentile (27.2 °C), the 21-day cumulative relative risk is 1.21 (95% uncertainty interval: 1.17–1.26), while that for 0–3 days is 1.28. The displaced (forward-shifted) fraction is 0.23 (0.10–0.36), and ranges from 0.22 to 0.39 in the 4- and 10-degree-of-freedom versions of the time trend. Heat-attributed mortality is a backward-calculated attribution for days with temperatures above 21.9 °C, with an empirical uncertainty interval calculated from 1,000 simulations; the average for the sample years is 1,028, and for 2024 it is 2,287 (1,876–2,713). The analysis plan was specified prior to the run. An independent re-analysis (using a different model family, its own code and raw data) reproduced the results within the pre-specified acceptance intervals. Cold-side estimates are not the subject of this analysis and are therefore not reported. ↩
92. Armstrong, B., Bell, M. L., de Sousa Zanotti Stagliorio Coelho, M., Leon Guo, Y. L., Guo, Y., Goodman, P. et al. (2017): *Longer-term impact of high and low temperature on mortality: an international study to clarify the length of mortality displacement*. Environmental Health Perspectives 125(10): 107009. DOI [10.1289/EHP1756](https://doi.org/10.1289/EHP1756). Based on annual mortality data from 278 locations across 12 countries. ↩
93. Central Statistical Office: *Demographic Yearbook 2024*, Table 6.2.27: X30 (harm caused by excessive heat of natural origin), 22 men and 5 women; in 25 cases, the cause of death was determined by post-mortem examination. ↩

94. Beck, T. M., Gudmundsson, L., Schumacher, D. L., Seneviratne, S. I., Achebak, H., Ballester, J. (2026): *Extreme event attribution for heat-related mortality due to anthropogenic climate change across Europe*. *Nature Health*, published 7 September 2026. DOI [10.1038/s44360-026-00193-z](https://doi.org/10.1038/s44360-026-00193-z). The Hungarian regional (NUTS2) figures are extracted from the source data table in the paper (Figure 3: probability ratio of the 2022 mortality event; Figure 1, panel d: the proportion of deaths attributable to heat during the week with the highest number of deaths in the summer of 2022); the figure of 26.5 for Southern Europe is taken from the abstract of the paper. The regional median is not a national estimate. ↩
95. Wu, X., Wang, J., Ge, Y., Lai, S., Zhang, D., Ren, Z., Wang, J. (2025): *Future heat-related mortality in Europe driven by compound day-night heatwaves and demographic shifts*. Nature Communications 16, 7420. DOI [10.1038/s41467-025-62871-y](https://doi.org/10.1038/s41467-025-62871-y). The figures refer to the baseline scenario without adaptation. ↩
96. Hajdu, T. (2025): *Heterogeneous impacts of climate change on morbidity*. Economics & Human Biology 58: 101517. DOI [10.1016/j.ehb.2025.101517](https://doi.org/10.1016/j.ehb.2025.101517). A random 50 per cent sample of the population, outpatient emergency cases, 2009–2017; the cumulative effect over eleven days compared with days with temperatures of 5–10 °C. ↩
97. Páldy A., Rudnai T., Beregszászi T. (2024): Assessment of heatwave plans in Hungarian social, child welfare and child protection institutions (2019–2021). Health Sciences 67(1): 4–27. DOI [10.29179/EgTud.2024.1.4-27](https://doi.org/10.29179/EgTud.2024.1.4-27). Social care institutions (2,052 institutions): 2019 survey; nurseries: 2021 survey; crèches: 2022 survey. ↩
98. Layton, J. B. et al. (2020): Heatwaves, medications, and heat-related hospitalisation in older Medicare beneficiaries with chronic conditions. PLoS One 15(12): e0243665. DOI [10.1371/journal.pone.0243665](https://doi.org/10.1371/journal.pone.0243665). Older Medicare beneficiaries; the authors found no synergy between medication and heatwaves. ↩
99. Chersich, M. F., Pham, M. D., Areal, A. et al. (2020): *Associations between high temperatures in pregnancy and risk of preterm birth, low birth weight, and stillbirths: systematic review and meta-analysis*. BMJ 371: m3811. DOI [10.1136/bmj.m3811](https://doi.org/10.1136/bmj.m3811). On prolonged exposure: Granés, L., Essers, E., Ballester, J. et al. (2024): *Early life cold and heat exposure impacts white matter development in children*. Nature Climate Change 14: 760–766. DOI [10.1038/s41558-024-02027-w](https://doi.org/10.1038/s41558-024-02027-w); Bonell, A. et al. (2024): Effect of heat stress in the first 1000 days of life on foetal and infant growth: a secondary analysis of the ENID randomised controlled trial. Lancet Planetary Health 8(10): e734–e743. DOI [10.1016/S2542-5196\(24\)00208-0](https://doi.org/10.1016/S2542-5196(24)00208-0) (Gambia, growth at 12 months of age, 90-day exposure); Adélaïde, L. et al. (2026): *Heat during pregnancy and reduced foetal growth*. Environmental Science & Technology. DOI [10.1021/acs.est.5c10602](https://doi.org/10.1021/acs.est.5c10602) (four French cohorts, weeks 2–15 of pregnancy). No European cohort confirms developmental effects of a few days of heat. ↩
100. Fatima, S. H., Rothmore, P., Giles, L. C., Varghese, B. M., Bi, P. (2021): *Extreme heat and occupational injuries in different climate zones: A systematic review and meta-analysis of epidemiological evidence*. Environment International 148: 106384. DOI [10.1016/j.envint.2021.106384](https://doi.org/10.1016/j.envint.2021.106384). National regulation: Joint Decree No. 3/2002 (8 February) of the Ministry of Social Affairs and Labour and the Ministry of Health, Section 7, as amended by Decree No. 63/2023 (28 December) of the Ministry of Economic Development. ↩
101. Metadata for the data layers of the National Adaptation Geoinformation System (NATÉR) and the HungaroMet KLIMADAT service. The legal basis for the system is Government Decree No. 94/2014 (21 March). The window and reference periods are taken from the service's own layer descriptions. The figure of 780 / 2000 / 5800 is taken from the underlying study, assuming unchanged vulnerability and population parameters. ↩
102. NATÉR, 'Daily excess mortality per 1 °C at micro-regional level, 2005–2014', 'Threshold temperature at micro-regional level, 2005–2014' and 'Reliability category at micro-regional level' layers; retrieved from the HungaroMet map service on 21 September 2026, own compilation. In the sub-regional layer, missing values are denoted by –888; the statistics were compiled after excluding these. The baseline study is the Hungarian publication referred to in note 86. ↩

103. HCSO: *2022 Census*, final data, Table 1.2.2.2 (households by age composition). · Eurostat: 2011 Census, population by age group, NUTS3 (cens_11ag_r3), and population as at 1 January by age group, NUTS3 (demo_r_pjangrp3), downloaded on 27 September 2026. · Eurostat GISCO: NUTS 2021 boundaries, 1:1 million. Own calculation: every point in the national grid is assigned to the county it lies within; the 129 points lying outside the boundary line are assigned to the nearest county; person-extremely-hot-days are the national sum of the product of the county population aged 75+ and the county average number of extremely hot days; breakdown into components: population effect (population change $\times$ previous hazard), hazard effect (previous population $\times$ hazard change), interaction. The calculation was replicated by an independent review. [↔](#)
104. HungaroMet: KLIMADAT geoinformation system, version 2.0 (14 July 2026), urban layer (SURFEX; Budapest by district, Szeged); the service's graphical data table (HungaroMet: KLIMADAT – graphical data table, gis01.met.hu/server/rest/services/PROD_Klimadat/data_tables/MapServer/7), downloaded on 10 October 2026. Observed 30-year averages, 1996–2025, annual; indicators: excessively warm nights (daily minimum $> 20^{\circ}\text{C}$) and, in KLIMADAT's terminology, hot days (daily maximum $\geq 30^{\circ}\text{C}$). The national value is the service's nationally defined value. Own extract. [↔](#)
105. HungaroMet ODP, daily station observations (odp.met.hu/climate/observations_hungary/daily/, historical and recent), downloaded on 10 October 2026. Stations: Budapest city centre (44121, District II), Lágymányos (44505, District XI), Állatkert (44167, District XIV, from 2016), Újpest (44165, District IV), Pestszentlőrinc (44527, District XVIII); Szeged city centre (58102), Szeged outskirts (58104, 58113, 58116: same location, with a change in station number). Tropical night: daily minimum $> 20^{\circ}\text{C}$; 30°C day: daily maximum $\geq 30^{\circ}\text{C}$; only years with at least 90 per cent summer data completeness; 2026: 1 January – 9 October. The zoo average comprises 8 full years, while the Szeged inner city average comprises 9 full years (2024 is incomplete). The difference reported for 30°C days refers to those days on which the daily maximum in the outskirts reached 30°C (average of annual averages). Pest-szentlőrinc is a suburban, not a rural, station; therefore, the difference for Budapest is a lower estimate. Own calculation. [↔](#)
106. Pinke, Zs., Ács, T., Kalicz, P., Kern, Z., Jámbo, A. (2024): *Hotspots in the EU-27 and Economic Consequences of the 2022 Spring–Summer Drought*. EuroChoices 23(1): 28–33. DOI [10.1111/1746-692X.12423](https://doi.org/10.1111/1746-692X.12423). [↔](#)
107. AKI Institute of Agricultural Economics: *Series on the Evaluation of the Functioning of the Agricultural Risk Management System*, 2013–2024 (titles of volumes published up to 2018: *Evaluation of the Functioning of the Agricultural Risk Management System*); figures for 2022–2024 are taken from Table 3 of the 2024 volume (DOI [10.7896/ai2504](https://doi.org/10.7896/ai2504)), while figures for earlier years are revised values from the subsequent volumes, based on MÁK and KMTR data. Between 2012 and 2024, the total amount of damage mitigation payments made was 162.8 billion forints. The volumes present the breakdown of insurance compensation by type of risk only in chart form. [↔](#)
108. State Audit Office (2024): *Report. Audit of the compliance of processes relating to grants awarded under the national agricultural damage mitigation scheme and of the operation of the national agricultural damage mitigation system*. 24157. According to the report, the management information system based on the agricultural risk management database does not serve as a basis for policy decisions, and the annual, county-level and damage-type-specific summaries required by law have not been produced. In the 2022 compensation year, 80 per cent of the compensation payments deemed eligible were paid out. [↔](#)
109. Pinke, Zs., Decsi, B., Kozma, Zs., Vári, Á., Lövei, G. L. (2020): *A spatially explicit analysis of wheat and maize yield sensitivity to changing groundwater levels in Hungary, 1961–2010*. Science of the Total Environment 715, 136555. DOI [10.1016/j.scitotenv.2020.136555](https://doi.org/10.1016/j.scitotenv.2020.136555). Daily records from 283 groundwater wells, county-level yield data, two 25-year periods (1961–1985 and 1986–2010). The yield time series are trend-removed using first-differencing to account for the effects of agrotechnological developments, and the regression coefficients are tested using bootstrap resampling. **There is a discrepancy within the paper itself: the summary states the proportion of explained variance as 18–38 per cent, while the discussion section gives a range of 10–38 per cent. We therefore specify the upper limit of the range—which is identical in both instances—and treat the lower limit as uncertain.** [↔](#)

110. Pinke, Zs., Decsi, B., Demeter, G., Kalicz, P., Kern, Z., Ács, T. (2024): *Continental lowlands face rising crop vulnerability: structural change in regional climate sensitivity of crop yields, Hungary (Central and Eastern Europe), 1921–2010*. Regional Environmental Change 24, 33. DOI [10.1007/s10113-024-02192-w](https://doi.org/10.1007/s10113-024-02192-w). Six homogenised station series, grid-point potential evapotranspiration, county-level yields; three non-overlapping 30-year windows, four bioclimatic regions, first-difference trend removal, bootstrap confidence interval. The authors themselves point out the limitation that they are working with monthly averages, while a few days of extremes may account for the majority of the variance in yield. ↩
111. Kern, A., Barcza, Z., Marjanović, H., Árendás, T., Fodor, N., Bónis, P., Bognár, P., Lichtenberger, J. (2018): *Statistical modelling of crop yield in Central Europe using climate data and remote sensing vegetation indices*. Agricultural and Forest Meteorology 260–261, 300–320. DOI [10.1016/j.agrformet.2018.06.009](https://doi.org/10.1016/j.agrformet.2018.06.009). Multiple linear regression for four crops, 2000–2016. Predictors include monthly fields from meteorological reanalysis and soil moisture, as well as annual fertiliser application to remove the trend. The explained variance is cross-validated; therefore, it does not represent the fit measured on the training set. **We have only processed the source at the level of metadata and summaries; we have not read the full text, so the figures can only be cited with this limitation.** ↩
112. Press releases from MVM Paksi Atomerőmű Zrt. (27 July – August 2026); in the press: Telex (28 July 2026), bne IntelliNews based on MTI (30 July 2026), Economx using data from the National Atomic Energy Agency (1 August 2026), Economx (6 and 31 August 2026). Reports differ regarding the most severe phase of the outage. The article dated 6 August mentions the shutdown of all four units, while the one dated 31 August refers to the shutdown of three units and the operation of one unit at half capacity. This is a secondary source and requires verification against the primary operational data sets (OAH, MAVIR). ↩
113. National Water Authority, Vigadó Square water gauge; in the press: the breaking of the negative record of 33 cm on 25 October 2018 (Pénzcentrum, 29 July 2026), reaching 0 cm (announcement by the Budapest Waterworks, Economx, 9 September 2026); the new low of –1 cm and the further drop in water levels in early October, as reported by the National Water Authority (Telex, 2 October 2026). The reference point of the gauge is not the riverbed; even at a water level of 3 cm, approximately 695 m³/s of water flowed through Budapest. ↩
114. Borsod-Abaúj-Zemplén County Government Office: Decision No. BO/32/02197-47/2025 on the integrated environmental permit for the Tiszaújváros site of MVM TISZA Power Plant Ltd. (April 2025), p. 53. ↩
115. VAHAVA Report (2010): *Climate Change and Hungary: Mitigating Risks and Preparing for Impacts*. Final report of the joint research programme between the Hungarian Academy of Sciences (MTA) and the Ministry of Environment and Water. We cite this because it is the only identified official Hungarian macro-level estimate, not because it is up to date. ↩
116. Fazekas, D., Goldman, M., Kőműves, Zs., Pavelka, A. (2021): *Climate impact assessment: Impacts of climate change scenarios on the Hungarian economy*. Final report for the Hungarian National Bank, Cambridge Econometrics, Budapest, May 2021. The study was prepared as input for the central bank's internal climate stress test. The impact of extreme weather events falls outside the scope of the study (Chapter 5). ↩
117. Traceability of the source chain in the project's internal documentation, analysis dated 25 and 27 August 2026. The original estimate relates to water-stressed regions and measures ecosystem service risk values – both the geographical scope and the quantities measured differ from those used in the Hungarian citations. ↩
118. European Environment Agency: *Economic losses from climate-related extremes in Europe, 1980–2024* (data release, fourth-quarter 2025 revision), broken down by country and year, at 2024 prices; the source data is from the CATDAT database. Downloaded on 27 September 2026. ↩

119. KSH STADAT Table 19.1.1.18: *Average yields of major arable crops*, kg/hectare, 1990–2025. Own calculations: deviation in average yield from the central seven-year rolling median (based on at least four years at the edges of the series); summer indices from the national homogenised grid. Of the nine tests, using Bonferroni correction ($p < 0.0056$), all three correlations for maize meet the threshold with a value of $p \leq 0.00002$, while neither of those for wheat nor sunflower do. Calculated using the E-OBS database, the maize coefficients are -0.68 , -0.65 and $+0.61$. The calculation was repeated by an independent verifier. ↩
120. The European Commission's Joint Research Centre's drought damage modelling (PESETA IV, Task 7, 2020) and the European Drought Risk Atlas (2024). These are treated as orders of magnitude. Using them as Hungarian design values would introduce the model conservatism that section H.2 is built to document. ↩
121. Act LVII of 1995 on Water Management (Vgtv.), Section 15(4)–(6). ↩
122. Forster, P. M. et al. (2026): *Indicators of Global Climate Change 2025: annual update of key indicators of the state of the climate system and human influence*. Earth System Science Data 18, 3889–3933. DOI [10.5194/essd-18-3889-2026](https://doi.org/10.5194/essd-18-3889-2026). (Earlier editions of the analysis cited the preprint, DOI [10.5194/essd-2026-287](https://doi.org/10.5194/essd-2026-287). The final article was published on 11 June 2026.) A set of indicators updated annually in accordance with the AR6 methodology; the 2025 edition introduces a new marine heatwave indicator and assesses the exceptional heat of 2023–2025 separately. The authors explicitly state that the observation infrastructure underpinning the indicators is at risk. ↩
123. Mauritsen, T., Tsushima, Y., Meyssignac, B., Loeb, N. G., Hakuba, M. et al. (2025): *Earth's Energy Imbalance More Than Doubled in Recent Decades*. AGU Advances. DOI [10.1029/2024AV001636](https://doi.org/10.1029/2024AV001636). Forty-four authors, representing virtually all relevant modelling and observation centres. The estimate is derived from satellite radiation measurements, cross-checked against ocean heat content measurements – the agreement between these two independent approaches lends weight to the finding. The paper does not propose a mechanism; it makes an observational, rather than an explanatory, statement. ↩
124. Loeb, N. G., Thorsen, T. J., Kato, S., Rose, F. G., Hodnebrog, Ø., Myhre, G. (2025): *Emerging hemispheric asymmetry of Earth's radiation*. PNAS. DOI [10.1073/pnas.2511595122](https://doi.org/10.1073/pnas.2511595122). · Ceppi, P., Wilson Kemsley, S., Andersen, H., Andrews, T., Kramer, R. J., Nowack, P., Wall, C. J., Zelinka, M. D. (2026): *Emerging low-cloud feedback and adjustment in global satellite observations*. Atmospheric Chemistry and Physics 26, 4153. DOI [10.5194/acp-26-4153-2026](https://doi.org/10.5194/acp-26-4153-2026). The twenty-year window values and the two-channel rate estimates are taken from the set of indicators listed in Note 122 (Section 6, Table 4). ↩
125. von Schuckmann, K. et al. (2020): *Heat stored in the Earth system: where does the energy go?* Earth System Science Data 12, 2013–2041. DOI [10.5194/essd-12-2013-2020](https://doi.org/10.5194/essd-12-2013-2020). · Cheng, L. et al. (2024): *New Record Ocean Temperatures and Related Climate Indicators in 2023*. Advances in Atmospheric Sciences. ↩
126. Cheng, L., Li, G., Long, S. M. et al. (2025): *Ocean stratification in a warming climate*. Nature Reviews Earth & Environment 6, 637–655. DOI [10.1038/s43017-025-00715-5](https://doi.org/10.1038/s43017-025-00715-5). · Liu, F., Song, F., Luo, Y. (2024): *Human-induced intensified seasonal cycle of sea surface temperature*. Nature Communications 15, 3948. DOI [10.1038/s41467-024-48381-3](https://doi.org/10.1038/s41467-024-48381-3). The mechanism is that the thinning mixed layer reduces the thermal inertia of the upper ocean, so that the same surface energy balance results in a greater change in surface temperature. ↩
127. Li, Z., England, M. H., Groeskamp, S. (2023): *Recent acceleration in global ocean heat accumulation by mode and intermediate waters*. Nature Communications 14, 6888. DOI [10.1038/s41467-023-42468-z](https://doi.org/10.1038/s41467-023-42468-z). · Johnson, G. C., Purkey, S. G. (2024): *Refined estimates of global ocean deep and abyssal decadal warming trends*. Geophysical Research Letters 51, e2024GL111229. DOI [10.1029/2024GL111229](https://doi.org/10.1029/2024GL111229). ↩
128. Pan, Y., Cheng, L. et al. (2026): *Ocean Heat Content Sets Another Record in 2025*. Advances in Atmospheric Sciences. DOI [10.1007/s00376-026-5876-0](https://doi.org/10.1007/s00376-026-5876-0). The 2025 sea surface temperature was the third warmest on record; the lower value compared with 2024 is explained by La Niña conditions. ↩

129. Smith, C., Walsh, T., Gillett, N., Hauser, M. et al. (2026): Indicators of Global Climate Change 2025 – effective radiative forcing time series, 1750–2025 (ClimateIndicator/forcing-timeseries data release), the forcing data layer for the indicator set mentioned in note 122. Zenodo DOI [10.5281/zenodo.20708818](https://doi.org/10.5281/zenodo.20708818). The decadal averages are our own calculations based on the aerosol and anthro aggregates; the anthro aggregate excludes the solar radiation and volcanic components. Unit: W/m², reference year 1750. ↩
130. Samset, B. H. et al. (2025): East Asian aerosol cleanup has likely contributed to the recent acceleration in global warming. *Communications Earth & Environment* 6, 543. DOI [10.1038/s43247-025-02527-3](https://doi.org/10.1038/s43247-025-02527-3). Multi-model runs from the Regional Aerosol Model Intercomparison Project (RAMIP). The title is replaced by a descriptive summary in this edition; the reference has been verified at DOI level. ↩
131. Sources for the separation of causes: Yuan, T. et al. (2024): Abrupt reduction in shipping emissions as an inadvertent geoengineering termination shock produces substantial radiative warming. *Communications Earth & Environment* 5, 281. DOI [10.1038/s43247-024-01442-3](https://doi.org/10.1038/s43247-024-01442-3); Gettelman, A. et al. (2024): Has Reducing Ship Emissions Brought Forward Global Warming? *Geophysical Research Letters* 51(15), e2024GL109077. DOI [10.1029/2024GL109077](https://doi.org/10.1029/2024GL109077); Zhang, J., Chen, Y.-S., Gryspeerdt, E., Yamaguchi, T., Feingold, G. (2025): Radiative forcing from the 2020 shipping fuel regulation is large but hard to detect. *Communications Earth & Environment* 6:18. DOI [10.1038/s43247-024-01911-9](https://doi.org/10.1038/s43247-024-01911-9). On the unexplained residual: Schmidt, G. (2024): Climate models cannot explain 2023's huge heat anomaly. *Nature* 627: 467. DOI [10.1038/d41586-024-00816-z](https://doi.org/10.1038/d41586-024-00816-z). ↩
132. Hansen, J. E. et al. (2023): *Global warming in the pipeline*. Oxford Open Climate Change. DOI [10.1093/oxfclm/kgad008](https://doi.org/10.1093/oxfclm/kgad008). By contrast, the current best estimate from the IPCC AR6 is 3 °C (likely range 2.5–4). **We present the debate but do not settle it. The higher estimates do not affect any of the values in the main text. Two references are missing in this section, and we note this: the satellite-based exclusion of low sensitivity is based on the cloud feedback studies cited in note 124, but the primary reference for the specific 2.5 °C threshold is not provided in this edition.** The source and year of the 4–5.3 °C range for palaeoclimatology are also missing. Both are to be added by the next edition – until then, the two statements are literature references, not cited values. ↩
133. O'Sullivan, M. et al. (2026): *An improved approach to estimate the natural land carbon sink*. *npj Climate and Atmospheric Science* 9, 29. DOI [10.1038/s41612-025-01302-7](https://doi.org/10.1038/s41612-025-01302-7). The correction reduces the natural terrestrial sink for the period 2015–2024 from 3.00 ± 0.94 to 2.42 ± 0.77 PgC/year. ↩
134. Friedlingstein, P., Le Quéré, C., O'Sullivan, M., Hauck, J. et al. (2026): *Emerging climate impact on carbon sinks in a consolidated carbon budget*. *Nature* 649: 98. DOI [10.1038/s41586-025-09802-5](https://doi.org/10.1038/s41586-025-09802-5). Ibid.: atmospheric carbon dioxide at 423 ppm in 2024; the oceanic sink is approximately 15 per cent larger than the terrestrial sink. ↩
135. Concentration and growth data: NOAA Global Monitoring Laboratory, globally averaged sea-surface measurement network (gml.noaa.gov). **Source criticism:** for the same year, different official analyses give varying annual increases (8.7 and 11.1 ppb for 2023 respectively) – different products, different averaging methods. The level is robust, but the increases cannot be directly compared; therefore, we report a range in this edition. ↩
136. Zhang, Z., Poulter, B., Wang, Z., Bruhwiler, L., Canadell, J. G. et al. (2026): Emergent constraints on future methane emissions from global wetlands. *Nature Geoscience* 19(6): 654–659. DOI [10.1038/s41561-026-01987-2](https://doi.org/10.1038/s41561-026-01987-2). A suite of seven terrestrial biosphere models, refined using 163 station-years of direct flux measurements. This refinement narrows the range for the 2090s from 120–475 to 218–388 Tg/year. The title is replaced by a content description in this edition; the reference has been verified at DOI level. The authors themselves point out the limitation that the majority of the measurements used for the narrowing of the range come from mid- and high-latitude regions, while approximately 68 per cent of the estimated increase is tropical. ↩

137. Fischer, E. M., Sippel, S., Knutti, R. (2021): *Increasing probability of record-shattering climate extremes*. Nature Climate Change. DOI [10.1038/s41558-021-01092-9](https://doi.org/10.1038/s41558-021-01092-9). · Kotz, M., Lange, S., Wenz, L., Levermann, A. (2023): *Constraining the Pattern and Magnitude of Projected Extreme Precipitation Change in a Multimodel Ensemble*. Journal of Climate. · Bevacqua, E., Fischer, E. M., Sillmann, J., Zscheischler, J. (2026): *Moderate global warming does not rule out extreme global climate outcomes*. Nature 651(8107): 946–953. DOI [10.1038/s41586-026-10237-9](https://doi.org/10.1038/s41586-026-10237-9). ↩
138. MacDougall, A. H. et al. (2020): *Is there warming in the pipeline? A multi-model analysis of the Zero Emissions Commitment from CO₂*. Biogeosciences 17, 2987–3016. DOI [10.5194/bg-17-2987-2020](https://doi.org/10.5194/bg-17-2987-2020). · Palazzo Corner, S. et al. (2023): *The Zero Emissions Commitment and climate stabilisation*. Frontiers in Science 1. DOI [10.3389/fsci.2023.1170744](https://doi.org/10.3389/fsci.2023.1170744). IPCC AR6 assessment: 0 ± 0.3 °C, with low confidence in the direction of the signal. In the ZECMIP experiment running eighteen models, the range across models of the temperature change expected fifty years on is between -0.36 and $+0.29$ °C. The ± 0.3 °C mentioned above is the range assessed in AR6, not the experimental standard deviation. ↩
139. Sanderson, B. M. et al. (2026): *Decomposition of the Zero Emissions Commitment into thermal warming pipeline and carbon buffering components*. EGUsphere, DOI [10.5194/egusphere-2026-1875](https://doi.org/10.5194/egusphere-2026-1875). **Preprint, under peer review** – the values cited from it are indicative orders of magnitude, not peer-reviewed references. Ten Earth system models from the flat10 experiment series, of which eight are carbon cycle-driven (negative ZEC) and two are heat-driven (positive). ↩
140. Trust, S., Saye, L., Bettis, O., Bedenham, G., Hampshire, O., Lenton, T. M., Abrams, J. F. (2025): *Planetary Solvency – finding our balance with nature*. Global risk management for human prosperity. Institute and Faculty of Actuaries and University of Exeter, January 2025. According to the report, risk management differs from the scientific approach in that, alongside the most likely outcome, it also estimates the worst-case scenario and its probability. Where estimates differ, it is considered prudent to use the highest damage estimate as the guiding principle until evidence proves it to be excessive. ↩
141. Foster, G., Rahmstorf, S. (2026): *Global warming has accelerated significantly*. Geophysical Research Letters 53, e2025GL118804. DOI [10.1029/2025GL118804](https://doi.org/10.1029/2025GL118804). The rate per data set: NASA 0.36, NOAA 0.36, HadCRU 0.34, Berkeley Earth 0.36, ERA5 0.42 °C per decade. Our own calculation: 1.37 °C + 0.27 °C per decade $\times 2.5$ decades ≈ 2.0 °C; with a rate of 0.34 , ≈ 2.2 °C; with a rate of 0.42 , ≈ 2.4 °C. The extrapolation reflects the level of anthropogenic warming, while the two faster rates stem from total warming net of natural variability. The mixed methodology serves to simplify the analysis. · IPCC (2021): *Summary for Policymakers*. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report. Cambridge University Press, 3–32. DOI [10.1017/9781009157896.001](https://doi.org/10.1017/9781009157896.001). Temperature values are taken from Table SPM.1; the description of the scenarios is taken from Box SPM.1. ↩
142. WMO (2026): *WMO Global Annual to Decadal Climate Update 2026–2035*. World Meteorological Organisation, Geneva, 28 May 2026. · Climate Change Committee (2026): *A Well-Adapted UK: The Fourth Independent Assessment of UK Climate Risk (CCRA4-IA)*. London, 20 May 2026; the 2 °C planning assumption and the 4 °C warning are on pages 14–15 of the executive summary. · Trust, S., Bettis, O., Orr, J., Abrams, J. F. et al. (2026): *Parasol Lost: Recovery plan needed*. Global risk management for human prosperity. Institute and Faculty of Actuaries, January 2026. According to the report, warming in excess of 2 °C is likely if the current trajectory remains unchanged. Warming of more than 3 °C by 2050 would require a combination of high climate sensitivity and sustained acceleration. The report presents the authors' views. ↩

143. The source for the carbon budget is Table 8 of the dataset referred to in Note 122 (Forster et al. 2026): 130 GtCO₂ for 1.5 °C, 500 GtCO₂ for 1.7 °C and 1,050 GtCO₂ for 2.0 °C, with a 50 per cent probability. Our own calculations: 130 / 42 ≈ 3, 500 / 42 ≈ 12, 1,050 / 42 = 25 years. · UNEP (2025): *Emissions Gap Report 2025: Off Target*. United Nations Environment Programme, Nairobi; press release: 4 November 2025; figures taken from the report's executive summary, levels that can be maintained with a 66 per cent probability. · Climate Action Tracker (2025): *Warming Projections Global Update, November 2025*. The 'pledges' row in the CAT table represents the 'pledges and targets' scenario, while the 'net zero' row represents the optimistic scenario, which assumes that all announced targets, including net-zero targets, will be met. · IEA (2025): *World Energy Outlook 2025*. International Energy Agency, Paris; source of temperature values: Evans, S., Nam, H. W. (2025): IEA: Fossil fuel use will peak before 2030 unless stated policies are abandoned. Carbon Brief, 12 November 2025. The figure shows the current policies (CPS) scenario. · Hausfather, Z. (2025): *An assessment of current policy scenarios over the 21st century and the reduced plausibility of high-emissions pathways*. Dialogues on Climate Change 2(1): 26–32. DOI [10.1177/29768659241304854](https://doi.org/10.1177/29768659241304854). The median value for current policies (2.7 °C) is taken from pages 27–28; the article does not provide values for other categories. · UNFCCC (2025): *2025 NDC Synthesis Report*. FCCC/PA/CMA/2025/8, 28 October 2025; the reduction target for the new commitments is 17 (11–24) per cent. The global figure of 12 per cent is from the update of 10 November 2025, based on the commitments of 113 Parties. The reductions required to limit warming to 2 °C and 1.5 °C are taken from the UNEP report. · UNEP (2026): *Limiting Overshoot: Navigating exceedance of 1.5°C and pathways towards return*. United Nations Environment Programme, Nairobi. DOI [10.59117/20.500.11822/49857](https://doi.org/10.59117/20.500.11822/49857). The rise due to the delay in peaking is from section 1.1 (p. 14); the trajectories that have become unfeasible, 2.6 and 1.8 °C, as well as the 20 per cent probability, are from section 1.2 (p. 17); the most stringent scenarios of 1.6–1.8 °C are from section 3.2 (p. 50). The 2.6 and 1.8 °C figures are median values; the 1.6–1.8 °C range refers to a 50 per cent probability. ↩
144. Engels, A., Marotzke, J., Gonçalves Gresse, E., López-Rivera, A., Pagnone, A., Wilkens, J. (eds.) (2023): *Hamburg Climate Futures Outlook 2023. The plausibility of a 1.5°C limit to global warming – Social drivers and physical processes*. Cluster of Excellence Climate, Climatic Change, and Society (CLICCS), University of Hamburg. DOI [10.25592/uhhfdm.11230](https://doi.org/10.25592/uhhfdm.11230). ↩
145. Palazzo Corner, S. et al. (2023): *The Zero Emissions Commitment and climate stabilisation*. Frontiers in Science 1. DOI [10.3389/fsci.2023.1170744](https://doi.org/10.3389/fsci.2023.1170744); the figure of 15 per cent and the findings regarding permafrost and peat originate from this source. The same source indicates that the spread of vegetation may offset carbon loss from permafrost, and that both processes are highly uncertain. · Lee, H., Kug, J.-S., Shin, Y., Lee, D.-G., Goris, N., Fröb, F., Tjiputra, J. F., Bourgeois, T., Schwinger, J. (2026): *Enhanced carbon loss in the Southern Ocean under mitigation scenarios*. Science Advances 12(36), eae9228. DOI [10.1126/sciadv.aee9228](https://doi.org/10.1126/sciadv.aee9228). An idealised experiment with a single Earth system model, in which emissions rise along the highest emission pathway (SSP5-8.5) until 2050, then cease by 2123. Ocean carbon uptake after emissions cease is approximately 0.5 billion tonnes of carbon per year, compared with approximately 2 billion tonnes today. · Frenger, I. et al. (2025): *Southern Ocean Heat Burp in a Cooling World*. AGU Advances 6(5), e2025AV001700. DOI [10.1029/2025AV001700](https://doi.org/10.1029/2025AV001700). In a model of medium complexity, the Southern Ocean suddenly releases its accumulated heat following several centuries of net negative emissions. This article is based on the publisher's summary. · UNEP (2026), note 143; the rate of cooling and the extent of removal are taken from section 1.4 (p. 20), the figure of a few tenths of a degree from the Executive summary (p. 6), and the scale of adaptation from the introduction to Chapter 1 (p. 13). ↩
146. Copernicus Climate Change Service, WMO (2026): *European State of the Climate 2025*. April 2026. The European figures refer only to land areas. ↩
147. Megyeri-Korotaj, O. (2024): *An analysis of future climate change and expected changes in Hungary in the 21st century*. Presentation, HungaroMet climate information workshop, 27 June 2024 (presentation; bibliographic details partially verified). The presentation indicates that the difference of 1–1.5 °C between the two period averages does not represent the change expected by 2050. · OMSZ, ELTE (2010): *Summary of expected climate trends in Hungary*. Hungarian Meteorological Service and Eötvös Loránd University, Budapest. ↩

148. OECD (2026): *Water Governance for Climate Resilience in Hungary*. OECD Publishing, Paris, January 2026. The source of the estimate for the Great Hungarian Plain is Mezósi, G. et al. (2014): *Climate Change Impacts on Environmental Hazards on the Great Hungarian Plain, Carpathian Basin*. *International Journal of Disaster Risk Science* 5(2): 136–146. DOI [10.1007/s13753-014-0016-3](https://doi.org/10.1007/s13753-014-0016-3), cited via the OECD report. · Hungarian National Bank (2026): *Green Finance Report 2026*. Budapest. ↵
149. Hydrological Atlas of Switzerland, Plate 6.4: The Hydrological Significance of the European Alps, explanatory text, Table 3 (hydrologicalatlas.ch; undated web source, bibliographic details partially verified). · Weber, M., Braun, L., Mauser, W., Prasch, M. (2010): *Contribution of rain, snow and ice melt to the upper Danube discharge today and in the future*. *Geografia Fisica e Dinamica Quaternaria* 33(2): 221–230. According to the authors, the contribution of ice melt at Passau will be negligible after 2030. · Huss, M. (2011): *Present and future contribution of glacier storage change to runoff from macroscale drainage basins in Europe*. *Water Resources Research* 47(7). DOI [10.1029/2010WR010299](https://doi.org/10.1029/2010WR010299). ↵
150. Zekollari, H., Huss, M., Farinotti, D. (2019): *Modelling the future evolution of glaciers in the European Alps under the EURO-CORDEX RCM ensemble*. *The Cryosphere* 13: 1125–1146. DOI [10.5194/tc-13-1125-2019](https://doi.org/10.5194/tc-13-1125-2019). · Cook, S. J., Juvet, G., Millan, R., Rabatel, A., Zekollari, H., Dussailant, I. (2023): *Committed ice loss in the European Alps until 2050 using a deep-learning-aided 3D ice-flow model with data assimilation*. *Geophysical Research Letters* 50(23), e2023GL105029. DOI [10.1029/2023GL105029](https://doi.org/10.1029/2023GL105029). · Matti, M., Crespi, A., Bertoldi, G. et al. (2021): *Observed snow depth trends in the European Alps: 1971 to 2019*. *The Cryosphere* 15: 1343–1382. DOI [10.5194/tc-15-1343-2021](https://doi.org/10.5194/tc-15-1343-2021); average calculated from November to May across more than 800 stations. · GLAMOS – Glacier Monitoring Switzerland, SCNAT Cryosphere Observation Committee (2026): *Annual mass balance of Swiss glaciers in 2025/2026*, published 1 October 2026 (glamos.ch). The annual loss relates to Swiss ice volume, which accounts for around half of the Alpine ice; no separate annual volume balance is published for the Austrian glaciers in the Danube catchment area, though the Alpenverein's annual Gletscherbericht reports changes in length. The sources for the losses in 2022 (approximately 6 per cent) and 2023 (approximately 4 per cent) are the 2022 and 2023 reports from the same GLAMOS series. The cumulative loss 'since 2017' can be calculated annually from this series; the volume does not do this because we have not verified the exact values for the years 2017–2021. ↵
151. Stagl, J. C., Hattermann, F. F. (2015): *Impacts of Climate Change on the Hydrological Regime of the Danube River and Its Tributaries Using an Ensemble of Climate Scenarios*. *Water* 7: 6139–6172. DOI [10.3390/w7116139](https://doi.org/10.3390/w7116139); Table 2 and Chapter 5. · Probst, E., Mauser, W. (2023): *Climate Change Impacts on Water Resources in the Danube River Basin: A Hydrological Modelling Study Using EURO-CORDEX Climate Scenarios*. *Water* 15, 8. DOI [10.3390/w15010008](https://doi.org/10.3390/w15010008); Table 3. The range of winter growth is derived from the eight central values of the two studies (between +7 and +22.5 per cent). The 9 per cent summer decline in Bratislava cited in the main text is the average of the study's ENSEMBLES ensemble; in the three run groups based on ISI-MIP data, the decline ranges from 10 to 13 per cent. The annual average remains unchanged in the first and increases by 5–8 per cent in the second. ↵
152. Own calculations based on the Paks discharge series from the hydrographic database of the National Water Authority (1 January 1990 – 31 August 2026); daily average for the local calendar day, annual minimum within the 1 June – 30 August window. The four lowest values are: 2026 (726), 2003 (885), 2022 (942) and 2018 (954 m³/s). The frequency of readings varies over the period (from one or two readings per day to one every quarter of an hour), but this does not alter the ranking. ↵
153. Armstrong McKay, D. I., Staal, A., Abrams, J. F., Winkelmann, R., Sakschewski, B., Loriani, S., Fetzer, I., Cornell, S. E., Rockström, J., Lenton, T. M. (2022): *Exceeding 1.5°C global warming could trigger multiple climate tipping points*. *Science* 377(6611), eabn7950. DOI [10.1126/science.abn7950](https://doi.org/10.1126/science.abn7950). · Lenton, T. M. et al. (eds.) (2025): *Global Tipping Points Report 2025*. Global Systems Institute, University of Exeter, 13 October 2025; figures relating to the Atlantic Deep Current and the Amazon are taken from the text of the report. ↵

154. Fox-Kemper, B., Hewitt, H. T., Xiao, C. et al. (2021): *Ocean, Cryosphere and Sea Level Change*. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report, Chapter 9. Cambridge University Press. · Ditlevsen, P., Ditlevsen, S. (2023): *Warning of a forthcoming collapse of the Atlantic meridional overturning circulation*. *Nature Communications* 14, 4254. DOI [10.1038/s41467-023-39810-w](https://doi.org/10.1038/s41467-023-39810-w); correction: *Nature Communications* 16, 7794 (2025), DOI [10.1038/s41467-025-63201-y](https://doi.org/10.1038/s41467-025-63201-y). The central estimate following the authors' correction in 2025 is 2065, with a 95 per cent range of 2037–2109. · Baker, J. A., Bell, M. J., Jackson, L. C., Vallis, G. K., Watson, A. J., Wood, R. A. (2025): *Continued Atlantic overturning circulation even under climate extremes*. Nature 638: 987–994. DOI [10.1038/s41586-024-08544-0](https://doi.org/10.1038/s41586-024-08544-0); in 34 models, the AMOC weakens even under extreme forcing, but does not collapse. · Swingedouw, D., Bily, A., Esquerdo, C., Borchert, L. F., Sgubin, G., Mignot, J., Menary, M. (2021): *On the risk of abrupt changes in the North Atlantic subpolar gyre in CMIP6 models*. Annals of the New York Academy of Sciences 1504: 187–201. DOI [10.1111/nyas.14659](https://doi.org/10.1111/nyas.14659); the risk of cooling associated with a sudden cessation of deep mixing in the subpolar gyre is at most 36.4 per cent in the latest generation of models. · Van Westen, R. M., Dijkstra, H. A. (2026): *Abrupt Gulf Stream path changes are a precursor to a collapse of the Atlantic Meridional Overturning Circulation*. Communications Earth & Environment 7, 197. DOI [10.1038/s43247-026-03309-1](https://doi.org/10.1038/s43247-026-03309-1). ↵
155. Van Westen, R. M., Baatsen, M. L. J. (2025): *European temperature extremes under different AMOC scenarios in the Community Earth System Model*. Geophysical Research Letters 52(12), e2025GL114611. DOI [10.1029/2025GL114611](https://doi.org/10.1029/2025GL114611). · Van Westen, R. M., van der Wiel, K., Falkena, S. K. J., Selten, F. (2025): *Changing European hydroclimate under a collapsed AMOC in the Community Earth System Model*. Hydrology and Earth System Sciences 29: 6607–6630. DOI [10.5194/hess-29-6607-2025](https://doi.org/10.5194/hess-29-6607-2025). · Ionita, M., Nagavciuc, V., Scholz, P., Dima, M. (2022): *Long-term drought intensification over Europe driven by the weakening trend of the Atlantic Meridional Overturning Circulation*. Journal of Hydrology: Regional Studies 42, 101176. DOI [10.1016/j.ejrh.2022.101176](https://doi.org/10.1016/j.ejrh.2022.101176). · Bellomo, K. et al. (2023): *Impacts of a weakened AMOC on precipitation over the Euro-Atlantic region in the EC-Earth3 climate model*. Climate Dynamics 61: 3397–3416. DOI [10.1007/s00382-023-06754-2](https://doi.org/10.1007/s00382-023-06754-2). ↵
156. Möller, T., Högnér, A. E., Schleussner, C.-F., Bien, S., Kitzmann, N. H., Lamboll, R. D., Rogelj, J., Donges, J. F. et al. (2024): *Achieving net zero greenhouse gas emissions is critical to limit climate tipping risks*. *Nature Communications* 15, 6192. DOI [10.1038/s41467-024-49863-0](https://doi.org/10.1038/s41467-024-49863-0); the value in brackets refers to the 10–90 per cent range; the four elements are the two ice sheets, the AMOC and the Amazon. ↵
157. European Environment Agency (2024): *European Climate Risk Assessment*. EEA Report 01/2024, Copenhagen. · Kotz, M., Kuik, F., Lis, E., Nickel, C. (2024): *Global warming and heat extremes to enhance inflationary pressures*. Communications Earth & Environment 5, 116. DOI [10.1038/s43247-023-01173-x](https://doi.org/10.1038/s43247-023-01173-x). · Hebebrand, C., Glauber, J., Vos, R., Rice, B. (2026): *The Iran war's impacts on global fertiliser markets and food production*. IFPRI blog, 1 April 2026; policy brief, not peer-reviewed. · Hungarian National Bank (2026), see note 148. · OECD (2026), *ibid.* · UNEP (2026), see note 143; the figure for food production is taken from section 2.3 (p. 39), where the report refers to the study by Farah et al. (2025). ↵
158. Fischer, E. M., Sippel, S., Knutti, R. (2021): *Increasing probability of record-shattering climate extremes*. Nature Climate Change 11: 689–695. DOI [10.1038/s41558-021-01092-9](https://doi.org/10.1038/s41558-021-01092-9). ↵
159. Weitzman, M. L. (2009): *On Modelling and Interpreting the Economics of Catastrophic Climate Change*. Review of Economics and Statistics 91(1): 1–19; the statement regarding discounting is on page 1. The author himself describes his probability estimates as very rough order-of-magnitude estimates. ↵
160. Armstrong McKay, D. I. et al. (2022): *Exceeding 1.5°C global warming could trigger multiple climate tipping points*. Science 377(6611), eabn7950. DOI [10.1126/science.abn7950](https://doi.org/10.1126/science.abn7950). The domestic impacts of tipping points are discussed in section VII.6. ↵
161. Wagenaar, W. A., Sagaria, S. D. (1975): *Misperception of exponential growth*. Perception & Psychophysics 18(6): 416–422. DOI [10.3758/BF03204114](https://doi.org/10.3758/BF03204114). ↵

162. Lawrence, M., Homer-Dixon, T., Janzwood, S., Rockström, J., Renn, O., Donges, J. F. (2024): *Global polycrisis: the causal mechanisms of crisis entanglement*. Global Sustainability 7, e6, 1–16. DOI [10.1017/sus.2024.1](https://doi.org/10.1017/sus.2024.1). The definition is on page 2; the model of stress and triggering events is in section 4.1; and the three pathways of entanglement are described in sections 4.2–4.5 and shown in Figures 6 and 9. The authors regard the polycrisis threshold as a qualitative category and system boundaries as a matter of convention. ↩
163. Zscheischler, J., Westra, S., van den Hurk, B. J. J. M., Seneviratne, S. I., Ward, P. J., Pitman, A., AghaKouchak, A., Bresch, D. N., Leonard, M., Wahl, T., Zhang, X. (2018): *Future climate risk from compound events*. Nature Climate Change 8(6): 469–477. DOI [10.1038/s41558-018-0156-3](https://doi.org/10.1038/s41558-018-0156-3); the statement regarding underestimation is on pages 469–470. ↩
164. Zscheischler, J., Martius, O., Westra, S. et al. (2020): *A typology of compound weather and climate events*. Nature Reviews Earth & Environment 1(7): 333–347. DOI [10.1038/s43017-020-0060-z](https://doi.org/10.1038/s43017-020-0060-z). ↩
165. Pescaroli, G., Alexander, D. (2018): *Understanding Compound, Interconnected, Interacting, and Cascading Risks: A Holistic Framework*. Risk Analysis 38(11): 2245–2257. DOI [10.1111/risa.13128](https://doi.org/10.1111/risa.13128). ↩
166. Carter, T. R. et al. (2021): *A conceptual framework for cross-border impacts of climate change*. Global Environmental Change 69, 102307. DOI [10.1016/j.gloenvcha.2021.102307](https://doi.org/10.1016/j.gloenvcha.2021.102307). · Ringsmuth, A. K., Otto, I. M., van den Hurk, B. et al. (2022): *Lessons from COVID-19 for managing transboundary climate risks and building resilience*. *Climate Risk Management* 35, 100395. DOI [10.1016/j.crm.2022.100395](https://doi.org/10.1016/j.crm.2022.100395); the two examples are given in Table 2. ↩
167. Mach, K. J. et al. (2019): *Climate as a risk factor for armed conflict*. Nature 571: 193–197. DOI [10.1038/s41586-019-1300-6](https://doi.org/10.1038/s41586-019-1300-6); the weighting of factors is given in the abstract. · Ide, T., Brzoska, M., Donges, J. F., Schleussner, C.-F. (2020): *Multi-method evidence for when and how climate-related disasters contribute to armed conflict risk*. Global Environmental Change 62, 102063. DOI [10.1016/j.gloenvcha.2020.102063](https://doi.org/10.1016/j.gloenvcha.2020.102063). · Buhaug, H. (2015): *Climate–conflict research: some reflections on the way forward*. WIREs Climate Change 6(3): 269–275. DOI [10.1002/wcc.336](https://doi.org/10.1002/wcc.336); according to the author, the quantitative literature underestimates the role of institutions and the quality of governance. · Lamain, C. (2022): *Conflicting securities: contributions to a critical research agenda on climate security*. Globalizations 19(8): 1257–1272. ↩
168. Hoff, R., Sparks, R., Chester, M. et al. (2025): *Cascading failure propagation and perfect storms in interdependent infrastructures*. ASCE OPEN: Multidisciplinary Journal of Civil Engineering 3(1): 04025001. DOI [10.1061/AOMJAH.AOENG-0045](https://doi.org/10.1061/AOMJAH.AOENG-0045). A synthetic electricity and water supply model modelled on Phoenix. ↩
169. Laybourn, L., Evans, J., Dyke, J. (2023): *Derailment risk: A systems analysis that identifies risks which could derail the sustainability transition*. Earth System Dynamics 14: 1171–1182. DOI [10.5194/esd-14-1171-2023](https://doi.org/10.5194/esd-14-1171-2023). · Laybourn, L., Shread-Hewitt, B., Jonusas, D., De Meyer, K., Dyke, J. G. (2025): *Derailment risk: Why climate strategies might fail – and how to fix them*. Strategic Climate Risks Initiative, October 2025. · The six risk factors: Trust, S., Saye, L., Bettis, O., Bedenham, G., Hampshire, O., Lenton, T. M., Abrams, J. F. (2025): *Planetary Solvency – finding our balance with nature*. Institute and Faculty of Actuaries and University of Exeter, January 2025. ↩
170. Omer, H., Alon, N. (1994): *The continuity principle: A unified approach to disaster and trauma*. American Journal of Community Psychology 22(2): 273–287. DOI [10.1007/BF02506866](https://doi.org/10.1007/BF02506866); definition of normalcy bias in the abstract. · Drabek, T. E. (1986): *Human System Responses to Disaster: An Inventory of Sociological Findings*. Springer, New York. ↩
171. Flyvbjerg, B. (2006): *From Nobel Prize to Project Management: Getting Risks Right*. Project Management Journal 37(3): 5–15. Cost overrun rates are shown in Table 1; the distinction between the two causes is on pages 4–5 (according to the pagination of the arXiv version of the study). ↩
172. Stoknes, P. E. (2014): *Rethinking climate communications and the ‘psychological climate paradox’*. Energy Research & Social Science 1: 161–170. DOI [10.1016/j.erss.2014.03.007](https://doi.org/10.1016/j.erss.2014.03.007). · O’Neill, S. J., Nicholson-Cole, S. (2009): *‘Fear Won’t Do It’: Promoting Positive Engagement With Climate Change Through Visual and Iconic Representations*. Science Communication 30(3): 355–379. DOI [10.1177/1075547008329201](https://doi.org/10.1177/1075547008329201). ↩

173. Garrett, N., Sharot, T. (2016): *Optimistic update bias holds firm: Three tests of robustness following Shah et al.* Consciousness and Cognition. DOI [10.1016/j.concog.2016.10.013](https://doi.org/10.1016/j.concog.2016.10.013). The authors respond to methodological criticisms raised by Shah et al.; the debate remains ongoing. ↩
174. Laybourn, L. et al. (2024): *The Security Blind Spot: Cascading Climate Impacts and Tipping Points Threaten National Security*. IPPR, Chatham House, University of Exeter Global Systems Institute and SCRI, October 2024. ↩
175. Milly, P. C. D., Betancourt, J., Falkenmark, M., Hirsch, R. M., Kundzewicz, Z. W., Lettenmaier, D. P., Stouffer, R. J. (2008): *Stationarity Is Dead: Whither Water Management?* Science 319(5863): 573–574. DOI [10.1126/science.1151915](https://doi.org/10.1126/science.1151915). · Frank, A. B. et al. (2014): *Dealing with femtorisks in international relations*. Proceedings of the National Academy of Sciences 111(49): 17356–17362. DOI [10.1073/pnas.1400229111](https://doi.org/10.1073/pnas.1400229111); according to the authors, risk management methods that assume a stationary distribution and separate institutional responsibilities are at odds with what an interconnected, changing world demands. ↩
176. HM Government / Cabinet Office (2025): *National Risk Register 2025*. London, 16 January 2025; the management of chronic risks is discussed at the end of Chapter 2. ↩
177. Shepherd, T. G. et al. (2018): *Storylines: an alternative approach to representing uncertainty in physical aspects of climate change*. *Climatic Change* 151(3–4): 555–571. DOI [10.1007/s10584-018-2317-9](https://doi.org/10.1007/s10584-018-2317-9). ↩
178. Trust, S., Saye, L., Bettis, O., Bedenham, G., Hampshire, O., Lenton, T. M., Abrams, J. F. (2025): *Planetary Solvency – finding our balance with nature*. Institute and Faculty of Actuaries and University of Exeter, January 2025. ↩
179. Haasnoot, M., Kwakkel, J. H., Walker, W. E., ter Maat, J. (2013): *Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world*. Global Environmental Change 23(2): 485–498. DOI [10.1016/j.gloenvcha.2012.12.006](https://doi.org/10.1016/j.gloenvcha.2012.12.006). · Delta Programme Commissioner (2023): *Delta Programme 2024. Now for later*. The Hague, September 2023; Chapter 5. ↩
180. Heuer, R. J., Pherson, R. H. (2020): *Structured Analytic Techniques for Intelligence Analysis*. 3rd ed., CQ Press / SAGE. ISBN 978-1-5063-6893-1. · Chang, W., Berdini, E., Mandel, D. R., Tetlock, P. E. (2018): *Restructuring structured analytic techniques in intelligence*. Intelligence and National Security 33(3): 337–356. DOI [10.1080/02684527.2017.1400230](https://doi.org/10.1080/02684527.2017.1400230); according to the authors, the error-reducing effect of these techniques has not been sufficiently demonstrated. ↩
181. Holling, C. S. (1973): *Resilience and Stability of Ecological Systems*. Annual Review of Ecology and Systematics 4: 1–23. DOI [10.1146/annurev.es.04.110173.000245](https://doi.org/10.1146/annurev.es.04.110173.000245). · Woods, D. D. (2015): *Four concepts for resilience and the implications for the future of resilience engineering*. Reliability Engineering & System Safety 141: 5–9. DOI [10.1016/j.ress.2015.03.018](https://doi.org/10.1016/j.ress.2015.03.018). ↩
182. Niinistö, S. (2024): *Safer Together: Strengthening Europe’s Civilian and Military Preparedness and Readiness*. Report by the Special Adviser to the European Commission, October 2024; comprehensive risk assessment and built-in preparedness on page 17, 72-hour self-sufficiency on page 20. ↩
183. France (2026): *Decree No. 2026-23 of 23 January 2026 on the reference warming trajectory for adaptation to climate change*. JORF No. 021, 25 January 2026; Environmental Code R. 229-1 – R. 229-3. The trajectory projects a rise of +2 °C by 2030, +2.7 °C by 2050 and +4 °C by 2100 for mainland France, compared with pre-industrial levels. These are national figures and cannot be directly compared with the global levels set out in Section [IX.1](#). · Ministère de la Transition écologique (2026): press release on the reference warming scenario, 27 January 2026, p. 2. ↩
184. WHO Regional Office for Europe (2021): *Heat and health in the WHO European Region: updated evidence for effective prevention*. Copenhagen, ISBN 978 92 890 5540 6; Table 7 (EU-SILC, 2012). ↩
185. European Parliament and Council (2024): Directive (EU) 2024/1275 on the energy performance of buildings (recast); Article 7(6), Article 8(3), Annex V, point 2(h). ↩
186. HM Government (2021): *Approved Document O – Overheating*. 2021 edition, for use in England; effective from 15 June 2022, Requirement O1. ↩

187. Climate Change Committee (2026): *A Well-Adapted UK: The Fourth Independent Assessment of UK Climate Risk (CCRA4-IA)*. London, 20 May 2026; p. 14. [↔](#)
188. MITECO (2026): *2026–2030 Work Programme of the National Climate Change Adaptation Plan*. Draft, public consultation 12 June – 14 July 2026, Madrid; the national climate refuge network on pp. 47 and 187, and the 2023–2027 framework for public buildings and climate refuges (PIMA Refugios climáticos) on pp. 62–64. · MITECO (2021): *2021–2025 Work Programme of the National Climate Change Adaptation Plan*. Madrid, p. 19. [↔](#)
189. Joint Research Centre (2025): *The second-generation Eurocodes: key changes and benefits through design examples*. JRC144386, Publications Office of the European Union, doi:10.2760/3056713; EN 1991-1-3 6.1(3), EN 1991-1-4 6.2(2). [↔](#)
190. Germany (2023): *Federal Climate Adaptation Act (KAnG)* of 20 December 2023. Federal Law Gazette 2023 I No. 393, in force from 1 July 2024; Section 8(1) and (3). According to Section 13, the Act does not confer any direct right of action. [↔](#)
191. European Commission (2021): Delegated Regulation (EU) 2021/2139; OJ L 442, 9 December 2021, Annex I, Appendix A, pp. 140–141. [↔](#)
192. Spain (2021): *Law 7/2021 of 20 May on climate change and the energy transition*. BOE-A-2021-8447, consolidated text; Article 21(1)(c). According to the text published in the Official Gazette, the 2022 amendment to the building regulations contains provisions on mitigation. This is our own assessment; we have not examined the full text of the 2025 draft regulations. [↔](#)
193. Delta Programme Commissioner (2023): *Delta Programme 2024. Now for later*. The Hague, September 2023; Chapter 5. · Germany (2023): *Federal Climate Adaptation Act (KAnG)* of 20 December 2023. Federal Law Gazette 2023 I No. 393, in force from 1 July 2024; Section 12. [↔](#)
194. World Bank, European Commission (2021): *Economics for Disaster Prevention and Preparedness: Financial Risk and Opportunities to Build Resilience in Europe*. Washington DC – Brussels; Hungarian country data. According to the report, flood insurance cover for households is virtually non-existent. We did not verify the flood cover component of domestic home insurance policies. [↔](#)
195. Consorcio de Compensación de Seguros (2026): *Statistics: Extraordinary Risks. Data series 1971–2025*. Madrid; insured events are listed on page 8, and the largest claims on page 127. [↔](#)
196. Cour des comptes (2026): *Natural disaster insurance: a challenge for financial sustainability*. Paris, April 2026; the system's results are on pages 10–11, while reserves and the expected state call on the fund are on pages 11–12. [↔](#)
197. Cour des comptes (2026): *Natural disaster insurance: a challenge for financial sustainability*. Paris, April 2026; p. 13. [↔](#)
198. Yougova, D. (2026): *European integrated framework for climate resilience*. EPRS Briefing, PE 791.469, European Parliament, 2 September 2026. The Commission's proposal had not yet been published at the time of finalising this document. [↔](#)
199. European Commission (2026): Summary of EU Solidarity Fund interventions between 2002 and 2025 and the 2026 thresholds for major disasters. · Council Regulation (EC) No 2012/2002 establishing the European Union Solidarity Fund, consolidated version. [↔](#)
200. Spain (2021): *Law 7/2021 of 20 May on climate change and the energy transition*. BOE-A-2021-8447, consolidated text; Article 30(1) and (4). [↔](#)

201. Hadvári M. (2024): *Remote sensing observations*. Presentation, HungaroMet Open Day, 16 April 2024: 4 radiosondes per day, 00 and 12 UTC, Budapest and Szeged. · O’Sullivan, D., Pinto, J., Rivaben, N. (2025): *Preliminary results of the World Meteorological Organisation Uncrewed Aircraft Systems Demonstration Campaign (WMO UAS DC)*. EGU General Assembly 2025, EGU25-20826. DOI [10.5194/egusphere-egu25-20826](https://doi.org/10.5194/egusphere-egu25-20826). · Hervo, M., Romanens, G., Martucci, G., Weusthoff, T., Haeefe, A. (2023): *Evaluation of an Automatic Meteorological Drone Based on a 6-Month Measurement Campaign*. Atmosphere 14(9), 1382. DOI [10.3390/atmos14091382](https://doi.org/10.3390/atmos14091382). The temperature error (0.75 K) met the World Meteorological Organisation’s intermediate ‘breakthrough’ requirement level, while the specific humidity (8.3 per cent) met only the minimum level. ↩
202. OECC (2019): *Evaluation Report on the National Climate Change Adaptation Plan*. Spanish Office for Climate Change, LIFE SHARA, Madrid, p. 26. · Spain (2021): *Law 7/2021 of 20 May on climate change and the energy transition*. BOE-A-2021-8447, consolidated text; Article 17(5). · Germany (2023): *Federal Climate Adaptation Act (KAnG)* of 20 December 2023. BGBl. 2023 I No. 393, effective from 1 July 2024; Sections 3–5. ↩
203. Spain (2021): *Law 7/2021 of 20 May on climate change and the energy transition*. BOE-A-2021-8447, consolidated text; Article 18. · Climate Change Committee (2026): *A Well-Adapted UK: The Fourth Independent Assessment of UK Climate Risk (CCRA4-IA)*. London, 20 May 2026. ↩
204. France (2026): *Decree No. 2026-23 of 23 January 2026 on the reference warming trajectory for adaptation to climate change*. JORF No. 021, 25 January 2026; Environmental Code, R. 229-1 – R. 229-3. · Ministry for Ecological Transition (2026): press release on the reference warming trajectory, 27 January 2026, p. 5. ↩
205. MITECO (2021): *2021–2025 Work Programme of the National Climate Change Adaptation Plan*. Madrid, pp. 7–8. · MITECO (2026): *2026–2030 Work Programme of the National Climate Change Adaptation Plan*. Draft, public consultation 12 June – 14 July 2026, Madrid, p. 20. ↩
206. KSH: *Ratio of the working-age population to the elderly*. Sustainable Development Goals, indicator 4.19 (ksh.hu/sdg/4-19-sdg-1.html), 2021 data release: “Following a period of temporary stagnation, the ageing index will rise sharply in the coming period and is expected to reach 150 by 2035.” According to the medium variant of the population projection, the old-age dependency ratio will be 61.2 per cent in 2070. Downloaded on 5 October 2026. The actual change between 2011 and 2022 is reported in Section IV.2.
207. Copernicus Climate Change Service: *Development of C3S Decadal Prediction Service* (climate.copernicus.eu/development-c3s-decadal-prediction-service): the aim of the framework agreement is the regular production and publication of real-time decadal predictions using multiple global forecasting systems. Downloaded on 5 October 2026. Regarding the Augures run plan: project announcement, October 2026.
208. HungaroMet (2026): statement on total precipitation for January–September 2026 (251.7 mm, approximately 53 per cent of the 1991–2020 average of 471.1 mm; the driest such period since 1901), 6 October 2026; Cited in: Péncentrum, 6 October 2026 (pencentrum.hu/utazas/20261006/most-kozolte-a-hungaromet-tortenelmi-szarazsag-sujtja-az-orszagot-125-eve-nem-volt-pelda-ilyenre-1206806). Secondary source. ↩
209. HungaroMet: Observed domestic changes – precipitation indices (met.hu/eghajlat/eghajlatvaltozas/megfigyelt_hazai_valtozasok/csapadekindexek/), 1901–2025; Observed domestic changes – precipitation extremes (met.hu/eghajlat/eghajlatvaltozas/megfigyelt_hazai_valtozasok/homarseklet_es_csapadektrendek/csapadek_szelsosegek/), 1901–2020 and 1981–2020. ↩
210. Szabó P., Pongrácz R. (2026): Hungary is becoming drier while the annual total precipitation is barely decreasing. Másfélök, 19 August 2026. (masfelfok.hu/2026/08/19/magyarorszag-ugy-valik-szarazabb-eghajlatuva-hogy-kozben-alig-csokken-az-eves-csapadekosszeg/). The Thornthwaite classification method: Ács, F. et al., Theoretical and Applied Climatology, DOI [10.1007/s00704-014-1103-5](https://doi.org/10.1007/s00704-014-1103-5). Popular science article, not peer-reviewed. ↩

211. Pintér, K., Kertész, P., Balogh, J., Nagy, Z. (2019): Long-term evapotranspiration measurements at a semi-arid sandy grassland. EGU General Assembly 2019, EGU2019-16554 (conference abstract). ↩
212. Báder, L., Szilágyi, J. (2023): The widening gap between land evaporation and reference evapotranspiration implies increasing vulnerability to droughts in Hungary. *Periodica Polytechnica Civil Engineering* 67(4), 1028–1037. DOI [10.3311/PPci.21836](https://doi.org/10.3311/PPci.21836) ↩
213. Szilágyi, J., Báder, L., Józsa, J. (2025): Estimation of monthly land evaporation values in Hungary between 2000 and 2022 at kilometre resolution. *Hydrological Bulletin* 105(3), 4–12. DOI [10.59258/hk.20549](https://doi.org/10.59258/hk.20549) ↩
214. Szilágyi, J. (2026): Long-term water balance investigations in the Danube-Tisza Interfluvium of Hungary, Europe. Preprint, version 2, *engrXiv*. DOI [10.31224/7041](https://doi.org/10.31224/7041) (unreviewed). ↩
215. Kis, A., Szabó, P., Pongrácz, R. (2025): Analysis of detected and future drought conditions – a case study for the Great Hungarian Plain. *Theoretical and Applied Climatology* 156, 303. DOI [10.1007/s00704-025-05510-2](https://doi.org/10.1007/s00704-025-05510-2). The correlation between the drought index (PaDI) and summer precipitation is $r = -0.73$, while that with summer temperature is 0.62; according to the article's co-author, Péter Szabó (personal communication), the difference stems mainly from the index formula, which treats the two factors with nearly equal weight. ↩
216. Schumacher, D. L., Zachariah, M., Otto, F. et al. (2024): Detecting the human fingerprint in the summer 2022 western–central European soil drought. *Earth System Dynamics* 15, 131–154. DOI [10.5194/esd-15-131-2024](https://doi.org/10.5194/esd-15-131-2024) ↩
217. Szabó, A., Gribovski, Z., Kalicz, P., Szolgay, J., Gácsi, Zs., Bolla, B. (2024): An investigation into the effect of forest stands on groundwater recharge at the Kecskemét–Ménfőcsanak study site. *Agrokémia és Talajtan* 73(2), 133–150. DOI [10.1556/0088.2024.00168](https://doi.org/10.1556/0088.2024.00168) ↩
218. Zhuang, Y., Fu, R., Lisonbee, J., Sheffield, A. M., Parker, B. A., Deheza, G. (2024): Anthropogenic warming has ushered in an era of temperature-dominated droughts in the western United States. *Science Advances* 10, eadn9389. DOI [10.1126/sciadv.adn9389](https://doi.org/10.1126/sciadv.adn9389). In the western United States, since 2000, evaporative demand has accounted for approximately 62 per cent of the severity of meteorological drought. ↩
219. Ionita, M., Nagavciuc, V. (2026): From droughts to hotter droughts: Europe's changing hydroclimate. *Journal of Hydrology: Regional Studies*, 103684. DOI [10.1016/j.ejrh.2026.103684](https://doi.org/10.1016/j.ejrh.2026.103684). In Central and Southern Europe between 1902 and 2024, late-summer droughts were more severe than could be explained by changes in precipitation alone. ↩
220. Juhász Cséplő A. (2024): The effect of atmospheric and soil moisture content on fog formation. PhD thesis, University of Pécs, Doctoral School of Earth Sciences, pp. 51–54. ↩
221. Hausfather, Z. (2025): Comparing climate models with observations. *The Climate Brink*, 6 December 2025. (theclimatebrink.com/p/comparing-climate-models-with-observations). Blog post, not peer-reviewed: between 2001 and 2025, the observation lies at the upper end of the CMIP5 range, roughly in the middle of the CMIP6 range, and in the upper part of the latter for the past 15 years or so. ↩
222. Szabó P., Pongrácz R. (2026): County-level data reveal where heatwaves cause the greatest increase in mortality. *Másfélök*, 7 July 2026. (masfelfok.hu/2026/07/07/megmutatjak-a-megyei-adatok-hol-novelik-leginkabb-a-halalozast-a-hohullamok/). Weekly data for May–September, 2015–2025; popular science article, not peer-reviewed. ↩
223. Jin, Q., Pu, B. (2026): A recent doubling of the global warming rate signals a 1.5 °C breach by 2028. *npj Climate and Atmospheric Science*, DOI [10.1038/s41612-026-01561-y](https://doi.org/10.1038/s41612-026-01561-y). 'Article in Press' version. Five global datasets (HadCRUT, NOAA, Berkeley Earth, GISTEMP, CMST), linear extrapolation; the 1.5 °C threshold to be breached in 2028 (2026–2031), the 2 °C threshold in 2040 (2036–2051), and, at the longer-term rate of 0.20 °C per decade, in 2037 and 2062 respectively. ↩

224. NOAA Climate Prediction Centre (2026): ENSO: Recent Evolution, Current Status and Predictions / ENSO Diagnostic Discussion, 8 October 2026. (El Niño warning; Niño-3.4 anomaly approximately +2.1 °C; 83 per cent probability of a relative index of at least +2.5 °C – a historically strong event – for October–December) and 13 August 2026 (possibility of an event exceeding the strength of those recorded since 1950). cpc.ncep.noaa.gov ↩
225. Ineson, S., Scaife, A. A. (2009): The role of the stratosphere in the European climate response to El Niño. *Nature Geoscience* 2, 32–36. DOI [10.1038/ngeo381](https://doi.org/10.1038/ngeo381). Following a strong El Niño, late winter (January–March) tends to be cold and dry in Northern Europe, and mild and wet in Southern Europe, if the stratospheric polar vortex also weakens. ↩
226. Brands, S. (2017): Which ENSO teleconnections are robust to internal atmospheric variability? *Geophysical Research Letters* 44, 1483–1493. DOI [10.1002/2017GL073044](https://doi.org/10.1002/2017GL073044). The Southern European signal is barely distinguishable from internal atmospheric variability. ↩
227. King, M. P., Yu, E., Sillmann, J. (2020): Impact of strong and extreme El Niños on the European hydroclimate. *Tellus A* 72, 1704342. DOI [10.1080/16000870.2019.1704342](https://doi.org/10.1080/16000870.2019.1704342). During the strongest events, the direction of the Western European signal may even reverse. ↩
228. Drinking Water Quality 2011. Public Health Report, on the website of the National Centre for Public Health (nnk.gov.hu/attachments/article/726/Ivóvízminőség_2011.pdf), accessed on 15 October 2026. 92 per cent of Hungary’s drinking water supply comes from groundwater, and 8 per cent from surface water; by source type, 46 per cent is bank-filtered water, 35 per cent is confined groundwater, 11 per cent is protected karst water, and 8 per cent is surface water. These figures are from 2011; we were unable to find a more recent national breakdown by source type. ↩
229. Iturbide, M., Fernández, J., Gutiérrez, J. M. et al. (2021): Repository supporting the implementation of FAIR principles in the IPCC-WGI Atlas. Zenodo, DOI [10.5281/zenodo.3691645](https://doi.org/10.5281/zenodo.3691645) (github.com/IPCC-WG1/Atlas, regional average series). · Iturbide, M. et al. (2020): An update of IPCC climate reference regions for subcontinental analysis of climate model data. *Earth System Science Data* 12: 2959–2970. DOI [10.5194/essd-12-2959-2020](https://doi.org/10.5194/essd-12-2959-2020). Own calculations: one run each for 35 CMIP6 models, with up to three scenarios per model (SSP2-4.5, SSP3-7.0, SSP5-8.5); 98 runs at 2 °C, 85 at 2.5 °C, and 76 at 3 °C. The year in which the level is reached is defined as the first time the global 20-year moving average exceeds the 1850–1900 average; the regional value is the average for the corresponding 20-year period over the land areas of the Western and Central Europe (WCE) and Mediterranean (MED) reference regions. The range is defined as the 17th and 83rd percentiles of the runs. ↩
230. HungaroMet Open Data Policy portal (odp.met.hu): the national average of the homogenised daily temperature grid (1,233 grid points), 1971–2025; the annual mean temperature was 9.95 °C in 1971–1990 and 11.45 °C in 2006–2025. · NOAA National Centres for Environmental Information: NOAA GlobalTemp global annual surface temperature anomaly (GCAG series, from the github.com/datasets/global-temp mirror). Own calculation: the difference between the averages of the two twenty-year periods (national 1.51, global 0.70 °C, ratio 2.17). From the same series, the global average for 1991–2020 exceeded the 1850–1900 average by 0.90 °C; the 2, 2.5 and 3 °C levels are 1.1, 1.6 and 2.1 °C, respectively, in comparison. Measured against the models’ own 1991–2020 averages, they yield 1.2, 1.7 and 2.2 °C (Note 229). The amplification of the models for the same period is taken from the database in Note 229 (34 models, historical and SSP2-4.5 runs, within the range between the 17th and 83rd percentiles). The correction is 1.13 times the model values (2.17/1.92). The model value is the average for the Western and Central European region, not for Hungary; the correction is therefore an approximation. ↩

- 231.** Own calculation based on 28 runs of the bias-corrected FORESEE-HUN v1.0 projection (Note 10): national grid average, annual hot days (daily maximum $\geq 30^{\circ}\text{C}$), extremely hot days ($\geq 35^{\circ}\text{C}$) and tropical nights (daily minimum $\geq 20^{\circ}\text{C}$). The year in which the threshold is reached is derived from the global 20-year moving average of the driving global models (CNRM-CM5, EC-EARTH, HadGEM2-ES, IPSL-CM5A-MR, MPI-ESM-LR, NorESM1-M), according to the database in Note 229; the regional value is the average over the 20-year period, excluding the years prior to 2022. 28 runs at 2°C , 27 at 2.5°C , and 17 at 3°C ; the range is between the 17th and 83rd percentiles of the runs. The 28 runs comprise 14 regional–global model pairs on two emission pathways; only 17 runs reach the 3°C level by 2100, so the sample varies by level. For the EC-EARTH-based runs, the year of the level was taken from the r12i1p1 member. The measured values are our own calculations based on the HungaroMet homogenised daily grid (1,233 grid points, national average), consistent with the data in Section II. 1. ↩
- 232.** Zekollari, H., Schuster, L. et al. (2025): Glacier preservation doubled by limiting warming to 1.5°C versus 2.7°C . *Science* 388. DOI [10.1126/science.adu4675](https://doi.org/10.1126/science.adu4675). The global values are taken from the article, while the Alpine values are taken from the authors' May 2025 announcement (International Cryosphere Climate Initiative); both represent values at the point of equilibrium, not those for 2050 or 2100. ↩
- 233.** Rounce, D. R., Hock, R., Maussion, F. et al. (2023): Global glacier change in the 21st century: Every increase in temperature matters. *Science* 379(6627): 78–83. DOI [10.1126/science.aba1324](https://doi.org/10.1126/science.aba1324). ↩
- 234.** Drijfhout, S., Angevaere, J. R., Mecking, J., van Westen, R. M., Rahmstorf, S. (2025): Shutdown of the North Atlantic overturning circulation after 2100 following deep mixing collapse in CMIP6 projections. *Environmental Research Letters* 20(9), 094062. DOI [10.1088/1748-9326/adfa3b](https://doi.org/10.1088/1748-9326/adfa3b). ↩
- 235.** Terhaar, J., Vogt, L., Foukal, N. P. (2025): Atlantic overturning inferred from air–sea heat fluxes indicates no decline since the 1960s. *Nature Communications* 16. DOI [10.1038/s41467-024-55297-5](https://doi.org/10.1038/s41467-024-55297-5). ↩
- 236.** Cai, W., Borlace, S., Lengaigne, M. et al. (2014): Increasing frequency of extreme El Niño events due to greenhouse warming. *Nature Climate Change* 4: 111–116. DOI [10.1038/nclimate2100](https://doi.org/10.1038/nclimate2100). · Cai, W. et al. (2023): Anthropogenic impacts on twentieth-century ENSO variability changes. *Nature Reviews Earth & Environment* *. DOI [10.1038/s43017-023-00427-8](https://doi.org/10.1038/s43017-023-00427-8). No formal attribution study on the strength of the 2026 El Niño had been published by mid-October 2026. ↩
- 237.** Cissé, G., McLeman, R. et al. (2022): Health, Wellbeing, and the Changing Structure of Communities. In: *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report, Chapter 7*. Cambridge University Press. ↩
- 238.** Clement, V., Rigaud, K. K., de Sherbinin, A. et al. (2021): Groundswell Part 2: Acting on Internal Climate Migration. World Bank, Washington, DC. hdl.handle.net/10986/36248. ↩
- 239.** Hoffmann, R., Dimitrova, A., Muttarak, R., Crespo Cuaresma, J., Peisker, J. (2020): A meta-analysis of country-level studies on environmental change and migration. *Nature Climate Change* 10: 904–912. DOI [10.1038/s41558-020-0898-6](https://doi.org/10.1038/s41558-020-0898-6). ↩
- 240.** Missirian, A., Schlenker, W. (2017): Asylum applications respond to temperature fluctuations. *Science* 358(6370): 1610–1614. DOI [10.1126/science.aao0432](https://doi.org/10.1126/science.aao0432). The 28 per cent figure relates to the medium scenario (RCP4.5, approximately 1.8°C compared with 1986–2005), while the 188 per cent figure relates to the high scenario (RCP8.5); this estimate is disputed in the literature. ↩
- 241.** Kovács, A. D., Hoyk, E., Farkas, J. Zs. (2017): Homokhátság – a special rural area affected by drying in the Carpathian Basin, Hungary. *European Countryside* 9(1): 29–50. DOI [10.1515/euco-2017-0003](https://doi.org/10.1515/euco-2017-0003). ↩
- 242.** Aas, W., Mortier, A., Bowersox, V. et al. (2019): Global and regional trends of atmospheric sulphur. *Scientific Reports* 9: 953. DOI [10.1038/s41598-018-37304-0](https://doi.org/10.1038/s41598-018-37304-0). · Data for Hungary: HungaroMet (2025): Hungary Informative Inventory Report 1990–2023, the official emissions report under the Convention on Long-range Transboundary Air Pollution (EMEP/CEIP), Table ES.1 (legszenyvezett-seg.met.hu): sulphur dioxide – 832 thousand tonnes in 1990, 427 thousand tonnes in 2000, 42 thousand tonnes in 2005, 30 thousand tonnes in 2010 and 11 thousand tonnes in 2023. ↩

243. Nabat, P., Somot, S., Mallet, M. et al. (2014): Contribution of anthropogenic sulphate aerosols to the changing Euro-Mediterranean climate since 1980. *Geophysical Research Letters* 41(15): 5605–5611. DOI [10.1002/2014GL060798](https://doi.org/10.1002/2014GL060798). · Schumacher, D. L., Singh, J., Hauser, M., Fischer, E. M., Wild, M., Seneviratne, S. I. (2024): Exacerbated summer European warming not captured by climate models neglecting long-term aerosol changes. *Communications Earth & Environment* 5: 182. DOI [10.1038/s43247-024-01332-8](https://doi.org/10.1038/s43247-024-01332-8). · Glantz, P., Fawole, O., Ström, J., Wild, M., Noone, K. (2022): Unmasking the effects of aerosols on greenhouse warming over Europe. *Journal of Geophysical Research: Atmospheres* 127(22): e2021JD035889. DOI [10.1029/2021JD035889](https://doi.org/10.1029/2021JD035889). ↩
244. Dong, B., Sutton, R. T. (2025): Drivers and mechanisms contributing to excess warming in Europe during recent decades. *npj Climate and Atmospheric Science* 8: 41. DOI [10.1038/s41612-025-00930-3](https://doi.org/10.1038/s41612-025-00930-3). The authors point to a high degree of uncertainty due to shortcomings in the models' atmospheric circulation. ↩
245. Vautard, R., Cattiaux, J., Hap  , T. et al. (2023): Heat extremes in Western Europe increasing faster than simulated due to atmospheric circulation trends. *Nature Communications* 14: 6803. DOI [10.1038/s41467-023-42143-3](https://doi.org/10.1038/s41467-023-42143-3). · Yin, Z., Dong, B., Wei, W., Yang, S. (2024): Anthropogenic impacts on amplified mid-latitude European summer warming and the rapid increase in heatwaves in recent decades. *Geophysical Research Letters* 51(16). DOI [10.1029/2024GL108982](https://doi.org/10.1029/2024GL108982) (links the atmospheric circulation contribution to greenhouse gases, which would imply persistence). · Rold  n-G  mez, P. J., Donat, M. G., Marcet-Carbonell, G., Smith, D. M. (2026): Accelerated European summer warming driven by atmospheric circulation changes in response to aerosol forcing. *Geophysical Research Letters* 53(13). DOI [10.1029/2026GL122424](https://doi.org/10.1029/2026GL122424) (links the change in atmospheric circulation partly to a reduction in sulphur pollution, which would imply a temporary effect). ↩
246. Copernicus Climate Change Service (2024): Gridded dataset underpinning the Copernicus Interactive Climate Atlas. Copernicus Climate Data Store, DOI [10.24381/cds.h35hb680](https://doi.org/10.24381/cds.h35hb680), CC BY 4.0; EURO-CORDEX EUR-11, without bias correction, downloaded on 17 October 2026. Own calculation: 8 driving global models and 12 regional models, RCP2.6, RCP4.5 and RCP8.5; national average from the atlas cells closest to the 1,233 ODP grid points. The level year is based on the 20-year moving average of the global driving model (Note 229); for the EC-EARTH r1 and r3, and the MPI-ESM-LR r2 and r3 members, this corresponds to the year of the r12 and r1 members, respectively. 93–96 run–scenario pairs at 2  C, 90–93 at 2.5  C, and 78–79 at 3  C; the range corresponds to the 17th and 83rd percentiles. The values for extremely hot days (daily maximum   35  C; the atlas index counts days above 35  C, which corresponds to the same in the model data) and tropical nights (daily minimum > 20  C) represent the change relative to the run's own 1991–2020 average, added to the measured 1991–2020 national values (2.8 and 1.9 respectively). The measured values for 2021–2025 are taken from the HungaroMet homogenised daily grid (own calculations). ↩
247. Barnes, C., Masselot, P., Xi, D., Clarke, B., Rayner, A., Chen, X., Wang, R., Raju, E., Theokritoff, E., Mistry, M., Gasparrini, A., Otto, F., Vicedo-Cabrera, A. M., Konstantinoudis, G. (2026): Heat-related urban mortality attributable to human-induced climate change in Europe from 2000 to 2025. *Nature Health**, published 14 October 2026. DOI [10.1038/s44360-026-00209-8](https://doi.org/10.1038/s44360-026-00209-8). The figures for Hungarian cities are taken from Table 2 of the paper (the Hungarian cities included in the sample have a total population of 2.8 million; annual average of 393 [247–575] deaths, of which 217 [127–316] are attributable to warming), the 2025 figure for Budapest is taken from Supplementary Table 4 (210 [132–317], ratio 0.76 [0.55–0.89]), while the 2003 figure is taken from Supplementary Table 3 (153). The ranges in brackets represent 95 per cent empirical uncertainty intervals. The model assumes the baseline mortality rate, the temperature–mortality relationship and the population to be constant; it does not account for adaptation. ↩

248. Preliminary crop yield results for 2026. Cereals: Institute of Agricultural Economics (AKI): Information report on summer agricultural work, as at 13 August 2026 (winter wheat: 986.9 thousand hectares, 4.235 million tonnes, 4.3 t/ha; 2025: 5.5 t/ha). Maize and sunflowers: briefing by the Ministry of Agriculture and Food and the National Association of Cereal Growers following the meeting of the Harvest Coordination Committee, 23 September 2026 (State Secretary János Molnár, Chairman Tamás Petőházi; reports from Agrárszektor and Magyar Mezőgazdaság); according to the ministry's status report of 6 October, 1.2 million tonnes had been stored from 68 per cent of the maize area. Békés County: the meeting of the county harvest committee on 29 September 2026 (Chairman József Bozó; BEOL, 30 September 2026) and the statement to MTI by the Békés County Directorate of the National Agricultural Chamber (NAK) (16 October 2026). Previous years: KSH STADAT 19.1.2.5. (2022: 3.41 t/ha, 2.8 million tonnes; 2025: 5.27 t/ha, 3.9 million tonnes). For the European outlook, COCER-AL's September forecast puts Hungary's maize production at 1.9 million tonnes, compared with 3.8 million in 2025. All 2026 figures are provisional; the KSH's final crop yield figures will be published after the manuscript has been finalised. ↩
249. Thüringer, B. (2026): A statisztika szerint nem volt többlethalálozás a második nagy nyári hőhullámnál – de vajon miért? [According to the statistics there was no excess mortality during the second major summer heatwave – but why?] Telex, 18 October 2026. <https://telex.hu/techtud/2026/10/18/masodik-hohullam-tobbethalalozas-statisztika-ksh-ferenci-tamas>. The analysis was carried out by biostatistician Tamás Ferenci on KSH mortality data up to 30 August 2026 and checked against EuroMOMO data. Secondary report; we have not verified its methodology. By our own estimate, displaced (brought-forward) mortality accounts for only about a quarter of the short-term heat-related excess (Note 91). ↩

ANNEX E

E Limitations of the analysis and their impact on the conclusions

The analysis reflects the status of the specified data sources as at autumn 2026. The 2026 data are provisional. This annex outlines where the analysis may be incorrect and in what direction. A shortcoming in itself does not necessarily weaken the conclusion. The question is whether the error tends to underestimate or overestimate the risk. Issues not addressed in this analysis – such as the attribution of individual events, return periods, and aggregate national economic loss figures – are listed in [H.4](#). This annex is limited to reservations concerning the statements presented.

E.1 Limitations that mean the reported risk is likely to be an underestimate

- **The projection basis is that of the previous model generation.** Both the domestic regional model ensemble and the official climate products are based on models from the previous generation and two emission scenarios ([VII.8](#)). In terms of temperature, both domestic projection sets fall short of observed values. The risk implications of the model generation are discussed at the end of section [H.2](#). According to a preliminary test carried out on a statistically downscaled CMIP6 database, the observed summer warming also falls in the upper part of the range of the newer generation of global models. Over a single five-year window, only one model matches the change observed since 1995–2014 in summer daily maximum temperatures and the number of days reaching 30 °C; five models match the change in the number of days exceeding 25 °C ([H.2](#)). The test has not yet been carried out on domestic projections based on the newer generation of models. As both domestic datasets remain below the observed values, the official 2050 temperature values should be treated as lower-bound estimates ([VII.4](#)). The warming effect of aerosol clearing is also partially absent from the projections ([VI.2](#)).
- **Estimates of atmospheric drying lose the most accuracy in the most severe scenarios.** The projection database estimates atmospheric humidity from the minimum temperature. The estimate fails to capture around one-third of the observed summer increase in vapour pressure deficit and around half of it in heatwaves arriving on dried-out soil ([II.2](#)).
- **Where no measurements are available, the risk is not reflected in the figures.** A significant proportion of water abstraction, confined ground-

water extraction and soil moisture in the root zone remains unmeasured (III.2, IX.10). No damage or trends can be identified in these areas; however, this does not mean that none exist.

- **The data on the two components of risk – exposure and vulnerability – are out of date.** The official vulnerability map dates from 2005–2014 and is based on a static population (IV.2). Population ageing, however, is highly predictable: according to the medium scenario of the Hungarian Central Statistical Office’s (KSH) population projections, the ageing index (the number of elderly people per 100 children) will rise from 139 in 2021 to around 150 by 2035.²⁰⁶ The map does not take this increase into account; consequently, it underestimates the size of the exposed elderly population and, therefore, the future risk. What is genuinely unknown today is the level of vulnerability – that is, the extent to which heatwave warnings, air conditioning and public awareness have altered it since 2014.
- **The economic damage can only be quantified to a limited extent.** There is no official national economic damage assessment. The only recent domestic macroeconomic model estimate assesses gradual impacts, but not the damage caused by extreme events (V.1). The breakdown of insurance claims by risk type is only available in graphical form; therefore, we only provide figures for loss-mitigation payments (IV.3).
- **In some sectors, the risk chain stops at the hazard or exposure.** In the energy supply sector, in relation to the thermal load of settlements and buildings, frost, forests and flash floods, the analysis measures the hazard; however, exposure and loss cannot be quantified because the proportion of capacity dependent on cooling water, the exposure of plantations and forest stands, and the damage figures broken down by hazard type are not publicly available (II.3, II.4, II.6, III.5, IV.4, IX.7). In these areas, the more brief discussion indicates a lack of data, not a lower level of risk.

E.2 Limitations that may make certain statements appear stronger than they are

- **The short time series for recent years are subject to internal variability.** The five-year averages for 2021–2025 are striking, but five years are not enough to confirm a decade-long trend. The fifty-five-year trend for summer precipitation, for example, does not differ from zero (II.2). We therefore always present the short-term data alongside the long-term series.

- **The 2026 records are based on preliminary data for a single year.** The 2026 record for the dry period is based on the average of ten stations and preliminarily quality-checked data; this average is not identical to the national grid average (II.2). A single year does not constitute a trend, so it cannot be determined at present whether we are seeing an outlier or a turning point.
- **Changes to the monitoring network may distort the long-term series.** The network of stations underpinning the measured air humidity grid expanded from 60 to 107 stations in 1999. Claims regarding critical periods of air drying are therefore based on period averages, a comparison of days with and without a history of dry conditions, and stations where instrumentation has remained unchanged since 2002 (II.2).
- **The two databases used in the independent verification share the same network of stations.** Both the national grid and the E-OBS show warming in the 2020s, but both are based on the same stations. The verification using reanalysis data cannot be applied to this period due to the change in production methodology in 2021 (II.1).
- **Two of the minimum-rule indicators rest on a single projection set.** Spring frost and vapour pressure deficit are not reported by the official KLIMADAT; therefore, for these two indicators, only FORESEE-HUN shows an underestimation (H.2). Furthermore, for spring frost the rule holds only for the 14 runs of the moderate emissions scenario (H.2, II.3).
- **The trends in frost do not meet the criteria for a strict test correction.** Changes in spring frost are therefore presented in descriptive form, and we report the more narrow statement that can be verified by both summarisation methods (II.3).

E.3 Limitations whose direction is unknown

- **The decadal prediction is based on a single source.** Runs from two model families are available. The retrospective runs track summer temperature well, but this skill derives largely from the warming trend, and decadal skill after removal of the trend has not been demonstrated; for precipitation there is no skill (H.3). We have identified the source of the bias in only one member of the retrospective runs, and we have not yet processed the service provider's updated report (II.1). This limitation may be alleviated in the near future. As part of the Augures project, the National Observatory of Athens will produce similar forecasts using multiple model systems in the next round, while the Copernicus Climate Ser-

vice is developing a regular decadal prediction service based on multiple forecasting systems.²⁰⁷

- **The two domestic projection sets diverge from the measured values in opposite directions with regard to winter temperatures.** KLIMADAT predicts a warmer winter, while FORESEE-HUN predicts a colder one than measured (H.2); consequently, winter risks cannot be reliably inferred from either set.
- **The literature is divided on future changes in atmospheric circulation (II.5).** Both an increase and a decrease in the frequency of blocking patterns are possible, while only a single study breaks down the causes of aridity into components using a single model (II.2).
- **The cause of the decline in confined groundwater levels remains undetermined.** In the absence of time series for extraction, the climatic and abstraction effects cannot be distinguished (III.2).
- **The causes of sea-surface extremes in 2026 have yet to be separated. It is not known what proportion is due to sustained warming and what proportion to interannual variability,** as the official assessment of the year was not available at the time of finalisation (VI.1).
- **The outlook for 2050 is scenario- and model-dependent.** The values of the two opposing components of the post-net-zero temperature are derived from a preprint (VII.3), and the timing of the tipping points is uncertain (VII.6).
- **The mortality data for 2025–2026 are preliminary.** These may be revised as data become available later, and the process of obtaining an updated time series from the official data provider was still ongoing at the time of finalisation (IV.1).

E.4 Limitations of the internal checking of the analysis

The analysis was conducted with the support of artificial intelligence, and all its main variants were verified by an independent recalculation based on the raw data (G.6). The recalculation identifies coding, data handling and reading errors, but does not necessarily reveal blind spots arising from the common methodological approach. An exception is the analysis of daily mortality in Section IV.1, which was recalculated using a different model family. The entries in the glossary (Annex C) record the terminology specific to this analysis; they are not standard technical dictionary definitions.

E.5 What this means for the user

Most of the weaknesses listed tend to lead to an underestimation of risk: the outdated projection basis, the estimation of air humidity, the unmeasured quantities and the outdated vulnerability data all contribute to this. The risk of overestimation mainly relates to certain values from recent years; therefore, we always present these alongside the long-term series, and we do not base our design rules on a single year. From this, we conclude that the published planning levels are conservative rather than excessive. This assessment is our own judgement, not a measured result.

The state of domestic knowledge

This annex summarises who carries out measurements and research in Hungary in the various areas covered by the analysis, what we have drawn upon from this, and where domestic data is lacking. The table is not a comprehensive institutional inventory; it merely lists those sources on which the analysis is based, or whose absence we note.

Area	Who measures it, who researches it	What the material uses	Gaps
Temperature, precipitation	HungaroMet	homogenised daily grid, 1971–2025 (G.6)	the official climate service does not publish an annual layer (II.2)
Regional projection	ELTE, HUN-REN ATK (FORESEE-HUN)	28 runs, two emission scenarios (H.1, H.2)	Access per run is restricted; the range for the coming decade is extremely narrow
Official regional projection	HungaroMet (KLIMADAT)	four runs, two emission scenarios, 24 indicators (H.2, II.2, VII.4)	Values per run not reported; the number of rainy days is uncorrected; spring frost and vapour pressure deficit data are not available
Decadal climate prediction	no domestic research group; National Observatory of Athens	downscaled runs of two systems (II.1)	No domestic skill assessment
Groundwater, surface water	Water management service (OVF, water management directorates)	well series 2001–2026, discharge 2000–2026 (III.1)	The time series for water abstraction is not publicly available; the calendar of rating-curve revisions is not known
Total water storage	no domestic product; CSR, Copernicus	satellite gravimetry (III.1)	–
Soil moisture, rapid drought	KITE agrometeorological network (nearly 600 stations, at various depths); there is no official national time series	–	the length, quality and professional accessibility of the KITE time series are unverified; there is no official root zone time series with a five-day resolution, meaning that the main driver of crop damage cannot be officially measured (H.4)
Actual evaporation (soil and vegetation combined)	MATE (Zoltán Nagy, Krisztina Pintér; Bugac, eddy covariance station; in the process of joining the ICOS European monitoring network)	–	the Bugac time series and its trends are pending publication; the material does not utilise these time series

Area	Who measures it, who researches it	What the material uses	Gaps
Evaporation from open water surfaces (pan evaporation)	previously at agrometeorological stations; measurements have ceased	–	There is no ongoing domestic pan evaporation time series; the date of discontinuation is unknown; the KITE agrometeorological network (nearly 600 stations) does not measure evaporation
Heat and health	NNGYK (Anna Páldy and colleagues); KSH	national excess mortality time series 2011–2023; daily mortality and heat-related death statistics 2011–2024 (IV.1)	the series based on alert days ends in 2023; there are no cause-specific daily mortality or hospital admission data; the only national morbidity survey (emergency care admissions) ends in 2017 (IV.1); the vulnerability layer dates from 2005–2014
Agricultural damage	AKI; KSH	compensation payments, county-level average crop yield (III.1, V.2)	compensation does not cover the full loss
National economic loss	no official figures	EEA CATDAT-based damage series (V.2)	The only official domestic macro-estimate is sixteen years old; the 2021 model calculation does not include damage from extreme events (V.1)
Geoinformatics for adaptation	HungaroMet (NATÉR)	Exposure and vulnerability layers (IV.2)	the layers have not been updated since 2019



What risk analysis means and how it differs

G.1 The order of the questions is important

The same data, the same model, the same author – **yet the answer differs** depending on which question we ask first.

A **forecast** first asks: *what can be expected, what will happen?* – and only then: *how does this affect the interests of society?*

Risk analysis starts the other way round: *what could happen that would adversely affect society's interests?* – and only then does it examine the probability. As climate risk increases over time, the second question is precisely this: *how does the probability of an adverse outcome change as a function of time and human action?*

This distinction is not mere hair-splitting, as a commentary in **Nature** published in February 2026, authored by leading climate and risk researchers, points out that the international institutions have never produced a mandate-based global climate risk assessment. The IPCC reports are scientific assessments that focus on the findings for which there is the highest level of certainty. The issue, therefore, is not that the reports are flawed, but that they were not designed for risk assessment.⁴

The practical implication of this is that a scientific report is good if it provides the best estimate and openly acknowledges uncertainty, while a risk assessment is good if it enables decision-makers to understand **what can still be avoided** and what the cost would be if we fail to do so.

G.2 The three factors of risk

Risk is not the same as hazard. It is the product of three factors:

- **Hazard** – the physical event or condition (heatwave, drought, frost, low flows).
- **Exposure** – who and what is present where the hazard occurs (population, agricultural land, natural areas, building stock, infrastructure).
- **Vulnerability** – the extent of harm caused if the hazard occurs (age and health profile, building quality, the condition of the natural and built environment, income, insurance cover, reserves). This also includes adapt-

ive capacity, over which we have some influence; all the points for intervention are therefore to be found here.

We seek to avoid two pitfalls. One is that Hungarian materials dealing with climate change – including official ones – predominantly model the hazard, while the other two factors, exposure and vulnerability, are at best merely illustrated. If we update only the hazard, we are updating just one of the three factors of risk. The other pitfall stems from the fact that exposure and vulnerability are **not climate data**. Demographics, the building stock, infrastructure, income and insurance cover – these do not originate from climate models, and they are not compromised if the climate model is conservative. This layer is accessible and can be updated, while uncertainty on the hazard side remains high; so improvement here is cheap and quick. On the vulnerability side, moreover, there are also government decision points; building adaptive capacity, for example, is one such intervention.

G.3 The ‘reasonable worst-case scenario’

The standard tool used in public administration risk assessment is not the most likely scenario, but the reasonable worst-case scenario – once highly improbable scenarios have been ruled out. The UK National Risk Register assesses every risk in this manner and states that this is not a forecast, but a framework enabling proportionate planning.⁵

The same system also yields a lesson directly applicable to Hungary. British practice distinguishes between **acute** risk (a discrete event, requiring a disaster response) and **chronic** risk (ongoing erosion of the economy, the community, way of life and national security). Climate change is a chronic risk there. Since 2020, chronic risks have been excluded from the probabilistic national risk assessment, on the grounds that traditional probabilistic impact assessment is less effective for systemic and persistent risks. Instead, a foresight-based and systems-oriented methodology is applied. The same document states that chronic risks make acute risks more likely and more severe – citing climate change as an example.

Two conclusions follow from this. First, for a climate document with a ten-year time horizon, a purely probabilistic framework is insufficient, and the scenarios (Chapter VIII) are not optional additions but methodological necessities. Secondly – and this is a warning – if chronic risk is excluded from public discourse on risk, it becomes invisible to the public administration. Note that the British chronic risk analysis is itself classified; the public register merely publishes the list of topics. The British ex-

ample can therefore serve as a source for the methodology, but not for public disclosure.

G.4 How to read the diagrams

We use two types of diagram, and the two must not be confused.

(a) **Threshold-exceedance diagram.** The frequency or probability of a specified, non-arbitrary threshold being exceeded as a function of time. This is the format used in insurance, engineering and occupational health and safety risk assessment, and it shows which is the greatest risk.⁶ Where you see one of these, the threshold is specified in the caption.

(b) **Mechanism diagram (storyline).** An unfolding of a physically self-consistent process, **without assigning probabilities.** We use this where uncertainty is profound and the mechanism is what matters – for example, in questions of atmospheric flow. It does not say ‘this will happen’, but rather ‘this is how it works, and this is reasonably possible’.⁷

The choice of threshold is a value judgement, not a scientific statement. The annex sets out in a table the twelve thresholds used, indicating whether they are derived from observation or from a model, and whether the probability of crossing the threshold can be quantified or whether only a qualitative description can be provided.

G.5 The two types of error – and which is the more costly

There are two ways to make a mistake. **False alarm:** we prepare for something that does not happen. **Omission:** we fail to prepare for something that does happen.

Scientific practice traditionally regards a false alarm as the more serious error, and is therefore cautious. Risk management practice, by contrast, regards omission as the more serious, and therefore takes the worst-case scenario as its basis. The authors of the Nature commentary cited above themselves put it this way: scientists typically focus a great deal on avoiding false alarms, while risk management professionals are more concerned with not missing a devastating event.

This analysis follows the logic of risk management and openly acknowledges this. In a planning context, failure to act is the more costly mistake, because the consequences of a missed investment span decades and are partly irreversible, while the cost of unnecessary preparedness is one-off and visible. **This is not a scientific finding, but a value judge-**

ment. Anyone who considers a different weighting to be correct may draw different conclusions from the same data – and we do not regard this as an error; what we do consider important is that the different weighting is stated explicitly.

There is also an economic basis for this weighting. Climate damage does not increase uniformly with temperature, but at an accelerating rate – each additional degree costs more than the previous one, as physiological, tolerance and design thresholds are breached – and on an upward-curving cost curve, the expected value of the costs of the possible outcomes is greater than the cost of the middle outcome. If the planner plans for the central value and ignores the upper band, they are not simplifying neutrally, but systematically underestimating the expected loss, and all the more so the wider the band. This follows from a comparison of the sources cited above.

Finally, as this is often misunderstood, we emphasise that risk analysis is not a counsel of despair. It shows precisely which outcomes can still be avoided – that is, the scope for human action.

G.6 The data and methodology in a nutshell

The observational data come from a single source: the homogenised, interpolated, gridded daily database of HungaroMet's open data portal. The grid has a resolution of 0.1 degrees, contains 1,233 grid points across Hungary, and is available from 1971 onwards. The threshold indices report the number of times a threshold is exceeded rather than the measured value itself. The number of extremely hot days refers to days reaching 35 °C, while the number of tropical nights refers to nights on which the temperature does not fall below 20 °C. These are calculated separately at each grid point and only then averaged nationwide. Reversing the order would yield a different result, as averaging would obscure the differences between grid points. Suppose that on a given day, the daily maximum at one grid point is 34.9 °C and at the neighbouring point 35.1 °C. If calculated per grid point, only one of the two points exceeds the threshold; the average of the two points therefore results in half an 'extremely hot day'. If we were to average the figures first, the average of 35.0 °C would result in a full 'extremely hot day' (Annex B).

We estimate the trends using a linear least-squares fit, with a 95 per cent confidence interval. As a check, we also apply the robust Theil–Sen estimator. Both methods fit a trend to annual aggregates – the national mean and the number of threshold days – rather than to the distribution

of individual extreme values. The assumption of normality therefore applies to the residual term of the aggregate, and while this is permissible here given the large number of observations, it would not be so elsewhere. If the distribution of extreme values itself were the issue – say, the return level for a given precipitation intensity – linear fitting would not be appropriate, because such quantities asymptotically follow a generalised extreme value distribution (Gumbel–Weibull–Fréchet). We therefore do not report return levels, and treat extremes as the frequency of threshold crossings rather than as a fitted distribution (Annex C). As we carry out many parallel trend tests, we adjust the significance threshold according to the number of tests (Bonferroni correction). The tests form a single family for the entire analysis, rather than for each chapter individually. The number of observational and hydrological trend tests is 104; the corrected threshold is therefore $0.05/104$, which is approximately 0.0005. Consequently, a p-value below 0.05 or a confidence interval that does not cross zero is not, in itself, sufficient for a finding to be classified as ‘significant’ in this analysis⁸. Point 7 of Annex B specifies which statements meet the corrected threshold and which do not. Where a trend does not meet the corrected threshold, it is reported as an indication of direction, together with the p-value, without the ‘significant’ classification.

Comparing the model results with the measurements is the central procedure of the analysis. The question is whether the full range of the models covers the measured value. If even the most extreme model value does not reach the measured value, this is referred to as a lack of coverage. In this case, the lower end of the model range is not a conservative estimate but a lower bound, and the planning minimum is the observed value. This is known as the planning minimum rule (H.2). We verify the rule for each indicator: it holds for four indicators – temperature, the number of days reaching 30 °C, spring frost and the vapour pressure deficit – but not for several others. For the duration of dry spells, the level of intense precipitation and the number of days reaching 35 °C, the model range covers the measured value; therefore, there is no lower bound there, and the measured trend governs. For these indicators, therefore, the measurements and the model are in agreement, and the model results are not underestimates. The term ‘model’ can refer to three different products in this analysis, and Section H.1 lists all three: the FORESEE-HUN regional model ensemble, the official KLIMADAT projection from HungaroMet, and the decadal climate prediction.

We examine groundwater level trends at all wells in the national network of reference wells for which August measurements are available for at least twenty-two years between 2001 and 2026, including detailed well groups in six regional units, with a counterpart group in Western Transdanubia. To analyse cyclicity, we also use time series dating back to 1975. We estimate the level trend for each well and aggregate the results nationally, by water management authority and by regional unit (III.1). We monitor surface waters using daily discharge and water level data from the water management service's gauges.

How it was produced and how we verified it

The analysis was carried out with the support of artificial intelligence, under human supervision and with human approval. The processing code, the calculations and the first drafts of the text were produced from the raw data. Every step of the analysis and the main versions of the manuscript were then recalculated in a second, independent check. The verification was carried out in a separate session, without using the authors' calculations, using newly written code based on the raw data. The published values were compared with the text number by number. The verification only flags discrepancies; the decision on corrections and approval of the version is made by a human. Furthermore, in September 2026, a review specifically focused on error detection examined the entire material, including recalculations. This revealed, for example, that one trend value for spring frost could only be verified using one method of national aggregation, but not the other. Section II.3 therefore reports the narrower formulation.



How we know what we know – and where the limits lie

H.1 Four different things that are often mistaken for one another

THE FOUR CONCEPTS

- **Observation.** Homogenised grid-point data and station time series derived from domestic measurement data, from 1971 onwards. This forms the most robust basis for the analysis. Its drawback is that it shows the past, and there are breaks in the measurement series that need to be addressed. The observation data in this material consist of a single channel, the official open data portal's 0.1° homogenised daily grid, comprising 1,233 grid points.⁹
- **Regional climate model (projection).** This is not a weather forecast, but rather shows what the climate would be like over a 30-year period under a given emissions pathway. It cannot predict what the year 2029 will be like. The majority of official Hungarian products fall into this category. Two domestic datasets are available. Where the text uses the terms 'the regional model ensemble' or 'the 28 model runs', it refers to FORESEE-HUN, the bias-corrected EURO-CORDEX dataset produced by ELTE and the HUN-REN Agricultural Research Centre.¹⁰ Where 'the official projection' or 'KLIMADAT' is mentioned, this refers to the HungaroMet service: four runs of two regional models (ALADIN-Climate and REMO) under two emission scenarios.¹¹ Both belong to the same model generation that underpins the IPCC's Fifth Assessment Report.
- **Decadal climate prediction.** This is a data source that employs a completely new approach. The decadal climate prediction system does not provide a weather forecast – as this would be meaningless over a ten-year period – but rather describes the expected state of the climate for the next 10 years. The material uses runs downscaled to Hungary, produced by the National Observatory of Athens as part of the Augures project. The model is initialised using observed ocean and atmospheric conditions, so for the first few years it captures some **of the internal variability** as well as the forced trend. A product of this kind therefore already exists for the 2026–2035 period and is available in a processed form.¹²
- **Forecasting skill.** The mere existence of a forecast does not mean it is a good one. Skill is measured using hindcasts: the same procedure is run for past decades and compared with observed data. **Where forecasting skill has not been demonstrated, this is indicated, and the analysis does not rely on it.**

H.2 The rule of the planning minimum

The rule of the planning minimum (in short: the minimum rule) is the most important methodological decision in this paper, and most of the conclusions are based precisely on this.

Several independent checks arrive at the same result:

- **Station-level verification.** We compared the projections for 2021–2050 from five domestic regional modelling studies with actual measurements from 2021–2026 at eleven stations. The direction is correct, but the magnitude is **consistently underestimated**. The seasonal pattern is partly incorrect, as spring proved to be the season warming most slowly, not the fastest, as the models had indicated. The seasonal shift in precipitation is more pronounced than predicted.
- **Four indicators for which the model range does not cover the observations.** For temperature and the number of days reaching 30 °C, the two domestic projection sets – the 28-run FORESEE-HUN and HungaroMet’s four-run KLIMADAT service – consistently fall short of the observed values (the test results are presented at the end of this section). None of the 28 runs reaches the observed value for the vapour pressure deficit under either emissions scenario. We examined spring frost in the 14 runs of the moderate emissions scenario, and none of these reaches the observed value (II.3). A check calculation was run on the high-emissions scenario runs, but its output was not retained. According to its recorded result, the range of April–May frost days there (0.33–3.35 days per year) covers the observed normal (2.39) but not the value for the last five years (3.48); we therefore apply the rule for spring frost to the moderate scenario. KLIMADAT does not report the vapour pressure deficit or spring frost. This is not a single outlier but a structural feature.
- **Data provider confirmation.** A 2024 domestic continuity correction itself confirms that the models do not reproduce the warming of the region since 2000 (see Note 10).
- **Forcing normalisation.** An obvious counter-argument would be that the model underestimates because it received less greenhouse gas as input than actually entered the atmosphere. However, this can be ruled out because the model ensemble ran on a concentration-driven trajectory from which the measured atmospheric carbon dioxide levels deviated by an average of only 1.3 ppm between 2015 and 2025. Converted to radiative forcing, this represents roughly one per cent of the total anthropogenic forcing. For the same increase in forcing, the **observed domestic temperature response is 1.7–2.1 times the projected value**. The discrepancy therefore lies not in the input, but in the response.¹³

Two interrelated interpretations follow from this. (1) The lower end of the model range should be regarded as a lower limit. If a design standard or funding criterion refers to the lower end of the range as a ‘conservat-

ive’ value, it is in fact designing for the least likely best-case scenario. (2) **The planning minimum is the value already observed.** What has once been measured cannot be placed by adaptation planning into the realm of the impossible; the range is open at the top. The relationship between the two interpretations is illustrated in Figure II/10a by means of a single indicator – the vapour pressure deficit. The 2025–2034 range of the 28 runs lies entirely below the value already observed in 2021–2025; in other words, the model does not even predict a value for the coming decade as high as that which we have already measured over the past five years.

The minimum rule, however, is not a criticism of the models; in other words, it does not claim that ‘the models are wrong’. In the case of the vapour pressure deficit, for example, the valid interpretation is that the available projection is derived **in a way** that does not reflect the observed mechanism. This also means that the discrepancy can be corrected.

Without a further qualification, however, the minimum rule would become a dogma, as the rule must be verified on a variable-by-variable basis and is not universally valid. We present several indicators for which the rule does not hold. For the duration of dry spells, the FORESEE-HUN range covers the measurement, and the observed trend shows no lengthening until 2025 (II.2). For methodological reasons, the same layer of KLIMADAT cannot be used to address this issue (at the end of the section). However, during the growing season of 2026, a record was set on average across the ten stations that have been recording data since 1901; therefore, for design purposes, the planning event here is not the model range but the observed extreme value. In terms of intense precipitation, the model predicts *wetter conditions* than observed in the overlapping years (II.4). For the number of days reaching 35 °C, days with a daily mean temperature of 25 °C, and tropical nights, both projection sets cover the observed values. For temperature indicators, the number of days reaching 30 °C, spring frost and the vapour pressure deficit, the model falls short; the minimum rule applies to these. Quoting the rule without specifying the indicator would imply more than the analysis supports.

An obvious and serious objection to the above argument is that any discrepancies found in a small country’s fifty-five-year data series or selected indicators may be a regional artefact caused by grid resolution, landscape effects or the specific characteristics of the Carpathian Basin. This cannot be addressed using Hungarian data; however, on a global scale, Chapter VI provides an answer, as the global energy balance exhibits exactly the same pattern, and in that context **the issues of regional selec-**

tion and grid resolution do not even arise. Furthermore, a direct analogy can be found on a continental scale. None of the model simulations examined show the flow-driven trend of heat extremes in Western Europe (II.5). The global signal and the domestic finding that the model range does not cover the observations are, however, based on different mechanisms; thus, their coincidence merely indicates a broader connection and cannot be regarded as evidence. The global result therefore does not in any way calibrate the magnitude of the domestic values. The four global processes, without knowledge of which the Hungarian values cannot be accurately interpreted, are explained in Chapter VI.

The minimum rule on the two domestic projection sets

Two independent regional projection sets have been produced for Hungary, and the planning minimum rule is only valid if both are examined using the same test. One is the FORESEE-HUN database of the Department of Meteorology at ELTE and the HUN-REN Agricultural Research Centre: bias-corrected runs of fourteen European regional model chains under two emission scenarios, totalling 28 runs. The other is HungaroMet's official KLIMADAT service: four runs of two regional models under the same two scenarios, on a 10 km grid.

The two datasets were created for different purposes, and this results in different strengths. KLIMADAT provides twenty-four climate indicators as ready-to-use layers, at national, county and district level, and aligned with homogenised domestic observations; thus, this is a product that can be used directly for official planning. FORESEE-HUN provides a daily data series for each run; consequently, it allows for the calculation of quantities not included in the ready-made layer, such as the vapour pressure deficit, and its 28 runs capture the uncertainty arising from model selection more comprehensively. Both datasets have known weaknesses. The four KLIMADAT runs are based on two global models, and the service only reports the minimum, median and maximum values of the runs for each grid point. The range of the 28 FORESEE-HUN runs for the coming decade is extremely narrow – 0.1 °C for the annual mean temperature between 2022 and 2031 – which is consistent with the fact that the runs have been fitted to the observed data series. Neither dataset is ‘the better one’; the question is what they show for the same test.

The test has the same structure for both datasets and is deliberately biased in favour of the models. We compare the 2001–2030 range of KLIMADAT with the 1996–2025 observations, and the 2022–2031 range of FORESEE-HUN with the 2016–2025 observations. In both cases, the mod-

el window is five to six years later; thus, in a warming climate, the model has an inherent advantage. Each dataset is compared against its own observation series, as the two datasets derive the daily mean temperature differently. The absolute values of the two sets of columns can therefore only be compared with their own observations, not with each other. The lag indicates how many years later the median of the model runs reaches the level already attained by the measurements.¹⁴

indicator	KLIMADAT: measurement, 1996–2025	KLIMADAT: 4 runs, 2001–2030 (minimum – median – maximum)	KLIMADAT: lag, years	FORESEE-HUN: measurement, 2016–2025	FORESEE-HUN: 28 runs, 2022–2031 (minimum – median – maximum)	FORESEE-HUN: lag, years
annual mean temperature, °C	11.07	10.51 – 10.67 – 10.99 ▲	15.5	12.08	11.69 – 11.73 – 11.79 ▲	13.5
average summer temperature, °C	21.12	19.86 – 20.42 – 20.60 ▲	23.9	22.18	21.65 – 21.69 – 21.74 ▲	16.7
average spring temperature, °C	11.23	10.97 – 11.10 – 11.22 ≈	9.8	11.65	11.50 – 11.55 – 11.65 ≈	8.2
average winter temperature, °C	0.74	–0.24 – 0.86 – 1.75 ○	–	2.23	1.24 – 1.46 – 1.98 ▲	18.4
summer daily maximum, °C	27.71	25.35 – 26.43 – 26.85 ▲	46.0	28.84	28.20 – 28.25 – 28.30 ▲	17–22
Days reaching 30 °C, days/year	31.4	19.8 – 22.8 – 28.1 ▲	37.3	40.0	33.2 – 36.5 – 38.9 ▲	16.1
Days reaching 35 °C, days/year	3.8	1.6 – 2.8 – 4.8 ○	–	5.1	4.0 – 6.2 – 7.7 ○	–
days with a daily mean temperature of at least 25 °C, days/year	12.8	8.6 – 11.2 – 13.7 ○	–	18.0	15.2 – 18.0 – 21.1 ○	–
tropical nights, nights per year	2.8	2.4 – 4.2 – 6.0 ○	–	4.4	3.6 – 5.6 – 7.3 ○	–
days with sub-zero temperatures, days/year	87.3	74.5 – 85.8 – 97.2 ○	–	77.3	69.7 – 78.9 – 89.3 ○	–
Longest dry spell, days	27.0	24.0 – 25.2 – 26.5 ×	–	27.4	20.6 – 27.3 – 30.6 ○	–
days with precipitation (≥ 1 mm), days/year	90.0	97.3 – 116.6 – 136.6 ×	–	86.1	83.3 – 90.3 – 99.5 ○	–

Key: ▲ the measurement lies above the full range of runs, on the risk side; ≈ the measurement lies at the upper edge of the range; ○ the range covers the measurement; × the indicator is not suitable for this test due to

the correction procedure (see below). The delay is only shown where the range does not cover the measurement.

The result can be summarised in four points.

(1) In terms of temperature and the number of days reaching 30 °C, the two datasets consistently remain below the measured values. The annual and summer mean temperatures, the summer daily maximum, and the number of days reaching 30 °C are all above the full range of both datasets. In terms of the annual mean temperature, the median of the runs reaches the already measured level 15.5 years later in KLIMADAT and 13.5 years later in FORESEE-HUN; in summer, this occurs 24 and 17 years later, respectively. Two datasets, compiled independently and corrected using different methods, show the same results; therefore, the minimum rule for temperature is not a consequence of the choice of dataset. Following HungaroMet's terminology, we refer to days with a threshold of 30 °C as 'hot days' and those with a threshold of 35 °C as 'extremely hot days' (Annex C).

(2) Both datasets cover the measurement of the number of days reaching 35 °C. The same applies to days with a daily mean temperature of at least 25 °C, tropical nights and frost days; for the number of tropical nights, moreover, the median of both datasets is above the measured value. The minimum rule therefore cannot be applied to days with temperatures of 35 °C. Although the average for the last five years (8.5 days per year) is above the FORESEE-HUN 2022–2031 range, comparing a five-year average to a ten-year model average distorts the results to the model's disadvantage; when measured over windows of the same length, the figures remain within both ranges. This clarifies earlier versions of the document, which extended the minimum rule to days with temperatures of 35 °C.

(3) For winter temperature, the two datasets diverge in opposite directions. The KLIMADAT median indicates a warmer winter than measured, while every run of FORESEE-HUN indicates a colder one. When planning based on winter temperatures – heating demand, winter and frost protection capacity (II.4) – the two datasets diverge in opposite directions; therefore, the measured value serves as the starting point here as well. In spring, the measured values for both datasets are at the upper end of the range, which is consistent with the fact that spring is the season that warms up most slowly (II.1).

(4) The KLIMADAT projection layer is not conclusive regarding the duration of the dry period. The service adjusts precipitation to the observa-

tions using a monthly ratio, which corrects the monthly total but not the number of days with precipitation.¹¹ In the four runs, the number of days with at least 1 mm of precipitation is already around 27 days higher than the measured value in the 2001–2030 period; by contrast, the measured change between 1971–2000 and 1996–2025 is only +0.6 days. The 2023 assessment by HungaroMet staff also notes that the four simulations overestimate the number of days with precipitation, while slightly underestimating the summer dry spells.¹⁵ More frequent light precipitation artificially interrupts the dry spells. Therefore, the KLIMADAT dry-period range – above which the measured value lies, and which indicates a reduction of around four days in the future – does not provide conclusive evidence regarding the direction of change. All that can be concluded from this is that the measured value lies above the range. In FORESEE-HUN, the number of days with precipitation is close to the measured value, and the dry period range covers the measured value.

KLIMADAT does not report two indicators to which the minimum rule applies: spring frost (the number of frost days is only available on an annual basis) and the vapour pressure deficit. For these two indicators, the rule applies to only one dataset, FORESEE-HUN (II.2, II.3).

The 2026 update of KLIMADAT: a county, district and city test

HungaroMet updated the service in July 2026 (version 2.0).¹¹ The observation layer has been extended to 2025; the indicators are now available as county and district averages; and a new city layer has been added for Budapest (by district) and for Szeged. The basis of the projection has not changed; it continues to be the four regional runs described in the 2023 assessment.¹⁵ The urban layer was created using the SURFEX surface model, which is driven by these same four runs and reports only temperature indicators. The urban ‘observation’ is the sum of the homogenised grid and the modelled heat island; it is not a direct measurement.¹¹

The update has made it possible to repeat the above test for every county, district and Budapest borough. The test remains unchanged; that is, the measured average for 1996–2025 is compared with the range of the four runs for 2001–2030. The last two columns show what percentage of the measured change (1971–2000 → 1996–2025) is accounted for, on a national average, by the median of the runs and by the maximum value per grid point of the runs in the 2001–2030 window, respectively.¹⁶

indicator	county (20, including Budapest): measurement above the band	district (173): measurement above the band	Budapest district (23): measurement above the band	from the measured change: median	from the measured change: maximum value
annual mean temperature	15	123	5	59 %	92 %
average summer temperature	20	172	21	51%	63 %
summer daily maximum	20	173	23	29%	52 %
Days reaching 30 °C	16	136	21	40%	77 %
summer days (daily maximum > 25 °C)	20	173	23	13%	40%
average winter temperature	0	0	0	115 %	235 %
tropical nights	0 (below the band in 4)	1 (below the band in 69)	0	163%	245 %

The results can be summarised in three points.

(1) Broken down by region, the national result holds for the summer day-time indicators, and it is most pronounced there. None of the four runs reaches the measured levels of summer daily maximum temperatures or the number of summer days in any single county, district or borough. The median reflects less than a third of the measured change in summer daily maximum temperatures and an eighth of that in the number of summer days. The highest value of the runs – a measure favourable to the model – only reaches the national level for summer days between 1996 and 2025 (90 days per year) in the 2036–2065 window. The shortfall is therefore independent of the run selected, as even the warmest run falls short of the measured value. On two indicators the regional picture is mixed. For the annual mean temperature, the observed value lies above the range in 75 per cent of counties, 71 per cent of districts and only 22 per cent of Budapest boroughs; for days reaching 30 °C, in 79 per cent of districts. This is below the 80 per cent acceptance threshold fixed before the calculation, so we do not generalise regionally on these two indicators.

(2) **The picture is reversed at night and in winter.** For the number of tropical nights and the winter mean temperature, the runs show a greater change than measured; for frost days, the range covers the measured values. The model is therefore not generally ‘cold’, but rather misrepresents the ratio of daytime to night-time warming.

(3) **This error can be attributed to a mechanistic cause and is present in both domestic datasets.** According to the measurements, the daily temperature range – that is, the difference between the daily maximum and minimum – is increasing. In KLIMADAT’s own observation layer, it increased by an annual average of 0.42 °C, and by 0.63 °C in summer, between 1971–2000 and 1996–2025. An independent study by ELTE, using HungaroMet’s homogenised database, found the same result: between 1971–1990 and 2005–2024, the summer daily maximum rose by 2.6 °C and the minimum by 1.7 °C.¹⁷ By contrast, the median of the KLIMADAT runs indicates a narrowing of the temperature range, by 0.14 °C in summer for the period 2001–2030 and by 0.19 °C for 2021–2050. Of the 28 FORESEE-HUN runs, 27 also indicate a narrowing of the temperature range between 2022 and 2060 (II.2). In the same model, the increase in summer daily maximum temperatures is 0.16–0.21 °C per decade in the median of the runs, while the measured trend for 1971–2025 is 0.78 °C.¹⁶ The narrowing diurnal temperature range and weak daytime warming are consistent with the mechanism explained in the international literature by a lack of atmospheric clearing, i.e. the fact that, in the model, less solar radiation reaches the surface than in reality (see below). We have no quantitative estimate of the extent to which this explains the discrepancy in the two domestic datasets; we therefore treat it as an assumption. The two KLIMADAT models differ in this respect. According to HungaroMet’s description, ALADIN-Climate runs with time-varying aerosol forcing, while REMO runs with constant forcing; the authors themselves use this to explain why the summer warming in REMO is more moderate.¹⁸ However, the maximum values per grid point for the four runs also remain below the measured values for daytime indicators. Therefore, the variable aerosol forcing alone is unlikely to account for the difference.

What is specific to the HungaroMet dataset, and what is not. The underestimation of daytime warming is not a fault of the HungaroMet runs, but a common feature of CMIP5-based European regional modelling, as FORESEE-HUN also demonstrates. Three specific comments apply to KLIMADAT. (1) The 2026 update extended the observation period to 2025 but not the projection, and the service does not indicate that the measured values of the summer indicators for 1996–2025 in its own graphs lie above the range of the four runs. (2) The four runs are based on two global models, and only the minimum, median and maximum values are available per grid point; consequently, a member-by-member check cannot be carried out. (3) The temperature correction aligns the average of the runs with the 1971–2000 level, but the magnitude of the change is in-

herited from the model.¹¹ Threshold-based indicators therefore fully inherit the daytime trend shortfall. The continuity correction in FORESEE-HUN aligns the level with the measured series; consequently, it starts from a higher level in the coming decade, but this does not improve the trend either.

Planning implications. The county, district and borough layers of KLIMADAT do not provide planning values for the coming decade for daytime temperature indicators – mean summer temperature, summer daily maximum, summer days, and days reaching 30 °C (for days reaching 30 °C, the range still covers the observed value in about a fifth of counties and districts). For these indicators, the minimum value is the measured value for 1996–2025 or a more recent value. For night-time and winter indicators (tropical nights, days with frost, winter mean temperature), the layer can be used because it covers the measured values or exceeds them on the risk side. The Budapest district layer is valuable for describing the spatial pattern of the heat island (IV.2); however, the future summer level suffers from the same shortcoming as the regional layer.

The question of model generation: CMIP5 basis, CMIP6 world

Both domestic projection sets are based on the previous generation of global models. KLIMADAT's two regional models are driven by the CNRM-CM5 and MPI-ESM-LR global models,¹⁵ while FORESEE-HUN's fourteen model chains are also driven by the global models underpinning the IPCC's Fifth Assessment Report (CMIP5), under RCP scenarios.¹⁰ The decadal forecast used here, however, belongs to the newer generation (CMIP6) (II.1). We are therefore using outputs from two model generations simultaneously, and this carries certain risks.

What has changed in the new generation? The climate sensitivity of the CMIP6 models is spread across a wider range, and the upper end of the range has shifted higher. The 2.1–4.7 °C range (average 3.3 °C) of the CMIP5 models has widened to 1.8–5.6 °C (average 3.9 °C), and nine models exceed the highest value from the previous generation. The increase is primarily driven by stronger feedback from low cloud cover in the temperate zones.¹⁹ According to another summary, more than a quarter of the models have a sensitivity exceeding the highest CMIP5 value (4.7 °C), and around a fifth project warming of at least 5 °C in response to a doubling of carbon dioxide.²⁰ The IPCC's Sixth Assessment Report therefore did not simply adopt the raw model average, but weighted the models based on their agreement with observed historical warming and used a

simplified emulator. The assessed range is 2–5 °C (very likely), with the best estimate being 3 °C (VI.2).²⁰

Risk assessment: errors are possible in either direction.

- *There is a risk of underestimation based on CMIP5.* The domestic datasets do not include the high-sensitivity range of the new generation, so the upper end of the distribution is underrepresented in them. Even more serious is a regional modelling peculiarity that is independent of the global model generation. The majority of European regional model runs are conducted with a constant anthropogenic aerosol forcing. A comparison therefore shows that, across much of Europe, regional models project summer warming of 1.5–2 °C less by the end of the century than the global models driving them, and the absence of time-varying aerosols plays a decisive role in this.²¹ According to a 2024 study, summer temperatures across much of Western and Central Europe have risen three times faster than the global average since 1980, and the additional warming resulting from the decline in aerosols is more pronounced further east. Most model simulations do not reproduce this, because regional models run with constant aerosol forcing fail to account for the increase in radiation and warming caused by atmospheric clearing.²² The lag measured in the H.2 test – the median of the domestic runs lags behind the measurements by 17–24 years in summer – is consistent with this mechanism; however, we have not quantified the explained proportion, so this consistency does not prove causation.
- *There is a risk of overestimation if we switch to the raw CMIP6 average – and what remains of it in the light of the measurements.* Criticism of ‘hot models’ was raised in 2022, arguing that the predominance of high-sensitivity models skews the ensemble average and its uncertainty range upwards.²⁰ The years that have passed since then, during which the model trajectories have run into the period overlapping with observed data, have partially mitigated this criticism. On average, the CMIP6 projections cross the 1.5 °C global threshold 3–7 years later than observed data did in 2024. The timing is best reproduced by models that warm more rapidly and have moderately high sensitivity. The most extreme models, however, remain too fast; the model with the highest sensitivity under consideration projects the threshold being crossed 10–15 years earlier. Internal variability also played a role in the 2024 crossing.²³ According to another study, the record-breaking year of 2024 is not exceptional based on the CMIP6 ensemble, and this conclusion holds even after filtering out the ‘hot’ models.²⁴ However, the observational constraint for the future, based on data up to 2024, still places mid- and late-century warming within the

lower-to-middle range of the CMIP6 ensemble.²⁵ As the two results differ, we report both. In the current decade, the measurements point towards models with moderately high sensitivity, while the constraints for the middle of the century point towards the lower-middle range. This is the same open question as the two interpretations in Section VI.2, namely whether the acceleration stems from the phase-out of aerosol cooling or from higher sensitivity. Furthermore, in the comparison covering the period after 2015, the models are run under scenario constraints, while the actual decline in aerosol concentrations was – in our view – faster than this. The literature therefore continues to recommend that impact assessments should be based on global warming levels (1.5, 2, 3 and 4 °C) rather than time, or that models should be filtered according to the likely range of transient sensitivity of 1.4–2.2 °C. The high-sensitivity subset can be used to examine the range of extreme values, but only where the impact actually scales with global mean temperature.²⁰ When planning for the coming decade, excluding runs with moderately high sensitivity is not justified on the basis of the above. The picture is changing rapidly, and the years since 2022 have shifted the measurements upwards across the models. The observed global mean temperature between 2008 and 2022 typically lay below the raw CMIP6 average, rose slightly above it in 2024, and was practically on a par with it in 2025. Compared with the midpoint of the IPCC's performance-weighted trajectory, the observed temperature consistently lay higher in 2023–2025, while remaining within its range.²⁶ According to a publicly available comparison updated daily, the rate of warming measured since 2011 is 0.39 °C per decade, while the unfiltered CMIP6 ensemble average is 0.32 °C. However, calculated from 1970, the measured value of 0.21 °C is below the model average (0.24 °C).²⁷ The models underestimate the increase in the Earth's energy balance surplus between 2001 and 2019 by 10–40 per cent, and a significant proportion of this is attributable to the reduction in emissions of anthropogenic aerosols.²⁸ However, according to a 2026 study, all observed annual values—including the record-breaking year of 2023—fall within the range predicted by the models, and models with an equilibrium sensitivity of 3–5 °C reproduce the measurements most accurately.²⁹ Despite this discrepancy, the two sets of results lead to the same conclusion. In our view, the filtering criterion proposed in 2022—which also excluded models with moderately high sensitivity—appears overly cautious for the current decade, while the measurements still do not support the most extreme models. Furthermore, the global comparison obscures regional differences: in Western Europe, the models do not reproduce the

trend in heat extremes (II.5), while the domestic data misrepresent the ratio of daytime to night-time warming (above).

- The working model for decadal prediction: it is the measurement, not the label, that matters.* According to the developer, the equilibrium sensitivity of HadGEM3-GC3.1 is approximately 5.5 °C, while its transient sensitivity – which is more relevant on a decadal timescale – is approximately 2.7 °C.³⁰ High sensitivity is not in itself a reason for exclusion, as the quality of models varies greatly regardless of sensitivity. According to an analysis examining 18 models, global sensitivity has a weak influence on regional effects; therefore, selecting models solely on the basis of sensitivity is not justified.³¹ A high-sensitivity US model has been shown to have moderate transient sensitivity and to reproduce 20th-century warming well, while distorting palaeoclimate cold and warm periods.³² The question, therefore, is what HadGEM3 shows in comparison with observations, and the answer is twofold. On the one hand, in the large ensemble of the model's historical runs for 1850–2014, the warming since 1980 is consistently too strong, which the authors likely attribute to a positive bias in the transient sensitivity.³³ This is precisely the error that is significant in terms of the decadal trend. On the other hand, the forecast is initialised from the observed state; its retrospective runs track summer temperatures well (this skill derives largely from the trend, H.3), and the first observed year, 2025, ranks fourth from the coldest among the ten members (II.1). Therefore, no warming bias has been observed in the domestic data so far. The annual deviation of +1.7 °C is therefore not a lower limit, and due to the documented trend bias, it may fall towards the upper end of the possible range. However, this is not substantiated by the sensitivity label or the first year. Based on the above comparison, we recommend that the planning minimum be set at the observed 2020–2025 deviation (+1.1 °C), the planning value at +1.7 °C, and that the comparison be repeated annually.
- The claim that ‘models underestimate’ is not a universal rule.* Newer-generation global models show that, during the summers of 1951–2014, temperatures in Western Europe warmed less than observed, while in Eastern Europe they warmed more. Much of this difference is due to divergent air pressure trends, and there is considerable internal variability.³⁴ We therefore derive the domestic finding not from the international literature, but from the domestic test in H.2, on a per-indicator and per-dataset basis. We also carried out a similar analysis on 23 global models from a statistically downscaled CMIP6 database, using a single five-year window, comparing the 2021–2025 values with those of the 1995–2014 period. Only one model achieves the change measured since then in the summer daily

maximum and the number of days reaching 30 °C; five models achieve this for days above 25 °C, while the median of the models accounts for 41–50 per cent of the measured change. Over a five-year period, individual model runs show significant variation (with changes in the summer daily maximum ranging from –1.4 to +3.1 °C); therefore, the result is preliminary. A comparison based on levels is not conclusive due to the difference between the measured and modelled baseline levels.³⁵

What does this mean for planning? The minimum rule concerns the relationship between the datasets at hand and the measurements; therefore, a change in model generation does not invalidate it. The European regional ensemble driven by the new generation is already under development, and the German assessment is examining more than twenty regional simulations.³⁶ The first assessment runs of the next global generation (CMIP7) began in the spring of 2026. The historical forcing period extends to 2021; the main innovation is the emission-driven run, and seven new scenarios replace the old ones, with global warming of roughly between 1.5 and 3.5 °C by 2100.^{37,38} A European regional ensemble based on this is not expected before the second half of the decade. In our view, therefore, the CMIP6 regional ensemble is the most recent available basis for the coming years, and its use should not be postponed in anticipation of a later model generation. If domestic products switch to this, the same test must be repeated on them, and a separate check must be carried out to ensure that the aerosol forcing in the regional models follows that of the driving global model. For long-life facilities, it is advisable to link the planning level to the global warming level (**IX.1**: 2 °C baseline, 2.5 °C stress test), rather than to the calendar year of a particular model generation.

H.3 What we can and cannot infer from the decadal prediction

Key figures **from** the decadal prediction for the 2025–2034 period, relative to the 1991–2020 reference period (the aggregated values of the twenty members of the two model systems should not be confused with the figures used in Chapter II):

- annual mean temperature anomaly +1.3 ... +1.6 °C, rising to as much as +1.8 °C in summer;
- an increase in the number of extremely hot days (daily maximum ≥ 35 °C) of +6 days/year in the south, and +10–12 for the extreme members;
- annual precipitation +5 ... +15 mm, but more in winter and less in summer; the driest members –60 and –35 mm/year respectively.

To interpret these figures, we set out four conditions:

- The **deviations** are relative to a specific reference period (1991–2020) and are not absolute values. This reference period **is not the same** as that used by some of the official national climate projections. Confusion often arises from the mixing of different reference periods.
- In terms of temperature, the forecasting skill is significantly better than for precipitation.³⁹ The temperature skill, however, derives largely from the warming trend; decadal skill after removal of the trend has not been demonstrated. Because precipitation skill is weak, we treat the precipitation figures only as indicative, not as planning values.
- The above values are derived from the combination of two model systems that differ substantially from one another. In Chapter II, we therefore examine a single system suitable for use with domestic threshold indicators and present its values.
- The first year of the forecast (2025) already overlaps with the observations, and the significance of this will increase as time goes on. However, a single year is not sufficient to assess the decadal prediction, as the year-to-year variability in weather results in much greater variation for a single year than for the ten-year average. The observed year should therefore be positioned amongst the members of the forecast, rather than compared with the combined average (II.1).

H.4 What this material cannot tell you

- It does not tell us what the summer of 2029 will be like.
- It does not provide a return period ('once in a hundred years') – moreover, this concept is misleading in a non-stationary climate.
- It does not attribute individual events.
- It does not provide aggregate figures for damage to the national economy (see Chapter V).
- It gives no clear indication of future trends in atmospheric circulation – this is explained in section II.5, because it is precisely this lack of clarity that constitutes the key information.
- **It does not measure droughts that develop over a few weeks (flash droughts), which the international literature identifies as the main cause of crop damage.** Soil moisture collapse developing over a few pentads – that is, a few five-day periods – is not reflected in the duration of rainless periods or in the monthly indices. The pentad-scale, root-zone soil moisture percentile used to measure this is not included in the do-

mestic set of indicators. This phenomenon is by no means merely hypothetical. A formal attribution analysis based on Chinese data has also confirmed that 77 ± 26 per cent of the increase in the frequency of rapid droughts can be attributed to greenhouse gas-driven warming.⁴⁰ The global picture shows that the occurrence of droughts is accelerating on a sub-seasonal scale. The spread of rapid-onset droughts – which are the more common sub-type in regions with humid and semi-humid climates – can be detected in 74 per cent of the regions studied.⁴¹ Central Europe, and thus Hungary as well, is classified as being in the exposed zone based on the moisture classification. This conclusion is not a measured result; its verification through measurement remains a task to be carried out (II.2, VIII.7).

ABOUT THIS DOCUMENT

This document is a risk analysis. It examines what climate hazards, differing from the usual planning assumptions, may arise in Hungary over the next ten years, between 2026 and 2035; who and what they will affect; and for which decisions they matter. A risk analysis cannot predict exactly what will happen. What can be determined, however, is what we need to prepare for, and which mistake is more costly: unnecessary caution or a failure to prepare. The outlook extends to 2050. The analysis is based on domestic measurement series: the daily data maintained by HungaroMet since 1971, which have been homogenised and interpolated to grid points, as well as data series from the groundwater monitoring network and water gauges. These are compared with two domestic climate projection datasets (KLIMADAT, FORESEE-HUN), as well as with an international decadal climate prediction. Where the models do not even reach current measured conditions, the measured value serves as the starting point for planning. The method is described in Annex G, while the data and the verification of the calculations are set out in section G.6.

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