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A meso-scale simulation of future household water demand under climatic and socio-economic scenarios in Thuringia

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[HS5.3.1] Coupled human water systems: data-driven and socio-hydrological approaches to support water management, adaptation and governance

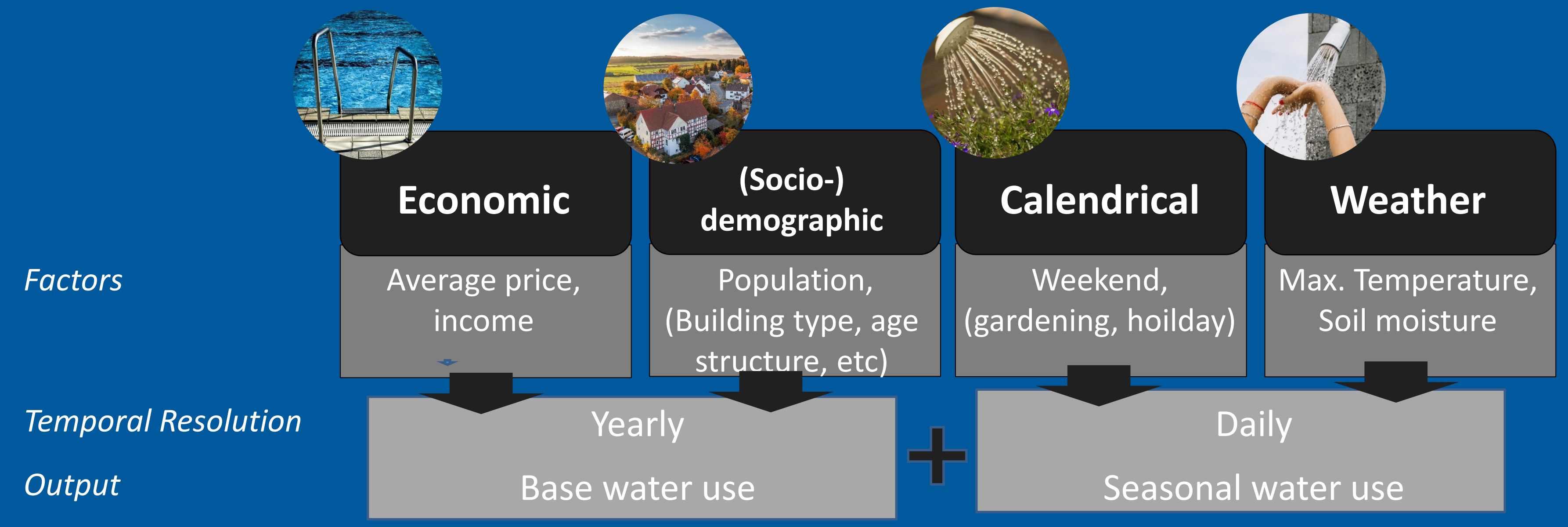
Background

- **Thuringia** is facing increased **water stress** due to **climate change**
- **Availability** of water resources and water use **conflicts** are **spatially and temporally heterogenous**
- Low water planning needs to evaluate **adaptation option** such as **demand management**
- This requires **knowledge** about the **drivers and future development** of water demand

Key research questions

- What are the **main drivers** of heterogenous **regional water demand**?
- How does regional water demand **evolve** under different **socio-climatic futures**?

Figure 1: Meso-scale model of regional water demand



	Economic	(Socio-) demographic	Calendrical	Weather
Factors	Average price, income	Population, (Building type, age structure, etc)	Weekend, (gardening, hoilday)	Max. Temperature, Soil moisture
Temporal Resolution	Yearly		Daily	
Output	Base water use		Seasonal water use	

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Methodology

(1) $\Delta W_d^T = W_d^{T\ seas} + W_d^{T\ temp} + W_d^{T\ wend} + W_d^{T\ pers}$

(2) $W_d^T = W_a^{T\ base} + \Delta W_d^T$

Overview of variables

T : Supply area

p_t: Average price in EUR/l

y_t: Available income in EUR

$\beta_{sdm}^T Z_t$: Coefficient vectors and matrix of socio-demographic variables: avrg. household size, age >65 years, building type (EFH, ZFH, MFH)

T_d^{max}: max. dail. Temperature; $D_{>25}$ Dummy for $T_d^{max} < 0$ deg. Cel.

SWC_d: natural log. of usable field capacity

θ_{1j}, θ_{2j}: Fourier coefficients (amplitudes), k: number of harmonic oscillations in fourier series

S_d : Dummy weekend

Calendrical cycle

$$W_d^{T\ seas} = \theta_0 + \sum_{j=1}^{k}\left[\theta_{1j}\cos\left(\frac{2\pi j}{365}d\right) + \theta_{2j}\sin\left(\frac{2\pi j}{365}d\right)\right]$$

Weather dependent cycle

$$W_d^{T\ temp} = \delta_1 T_d^{max} * D_{0<\&>25} + \delta_2 T_d^{max} * D_{>25} + \delta_3(SWC_d)$$

Weekend cylcle

$$W_d^{T\ wend} = \gamma_0 + \gamma_1 S_d$$

Autocorrelation

$$W_d^{T\ pers} = \varphi_0 + \sum_{i=1}^{p}\varphi_i X_{d-i}$$

Base water use (BWU) as econometric demand function

$$ln(W_t^{T\ base}) = \beta_0^T + \beta_{price}^T p_t + \beta_{income}^T \ln(y_t) + \beta_{sdm}^T Z_t$$

Monte-Carlo Simulation where water use is taken from the distribution $W = N(\widehat{W}_d^T, \sigma^2)$.

Parametrization/estimation method: Multivariate linear regression OLS-estimations (see Table 1).

Data sources

Seasonal daily use [m3/p/d]: Daily water discharge to households from a sample of water suppliers (see Figure 1). Base water use (BWU) is derived from mean water use at $T_d^{max} < 0$. Line losses are estimated as 24 * min. hour water discharge. Standard deviation of water use taken from daily water use sample. *Weather factors:* 1 km grid size historical daily weather from DWD CDC open data.

Average yearly water use [m3/p/a]: Unbalanced panel of supply areas (2004-2022). Total water consumption in from regional authorities, *Base Factors*: income, household type, building type, age from Mikrozensus, and price data from BDEW.

Figure 2: average water use of households in supply areas in Thuringia in 2020

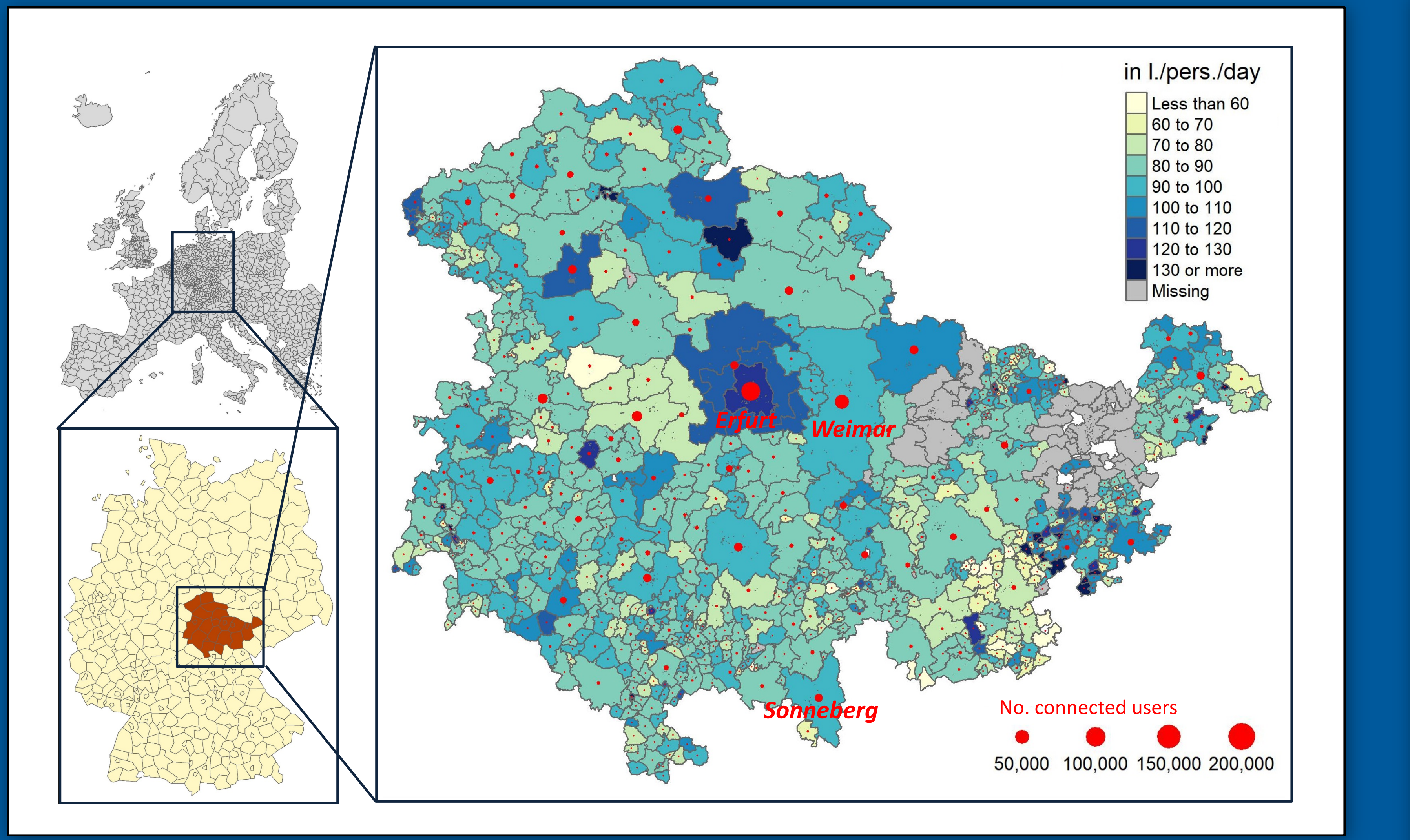
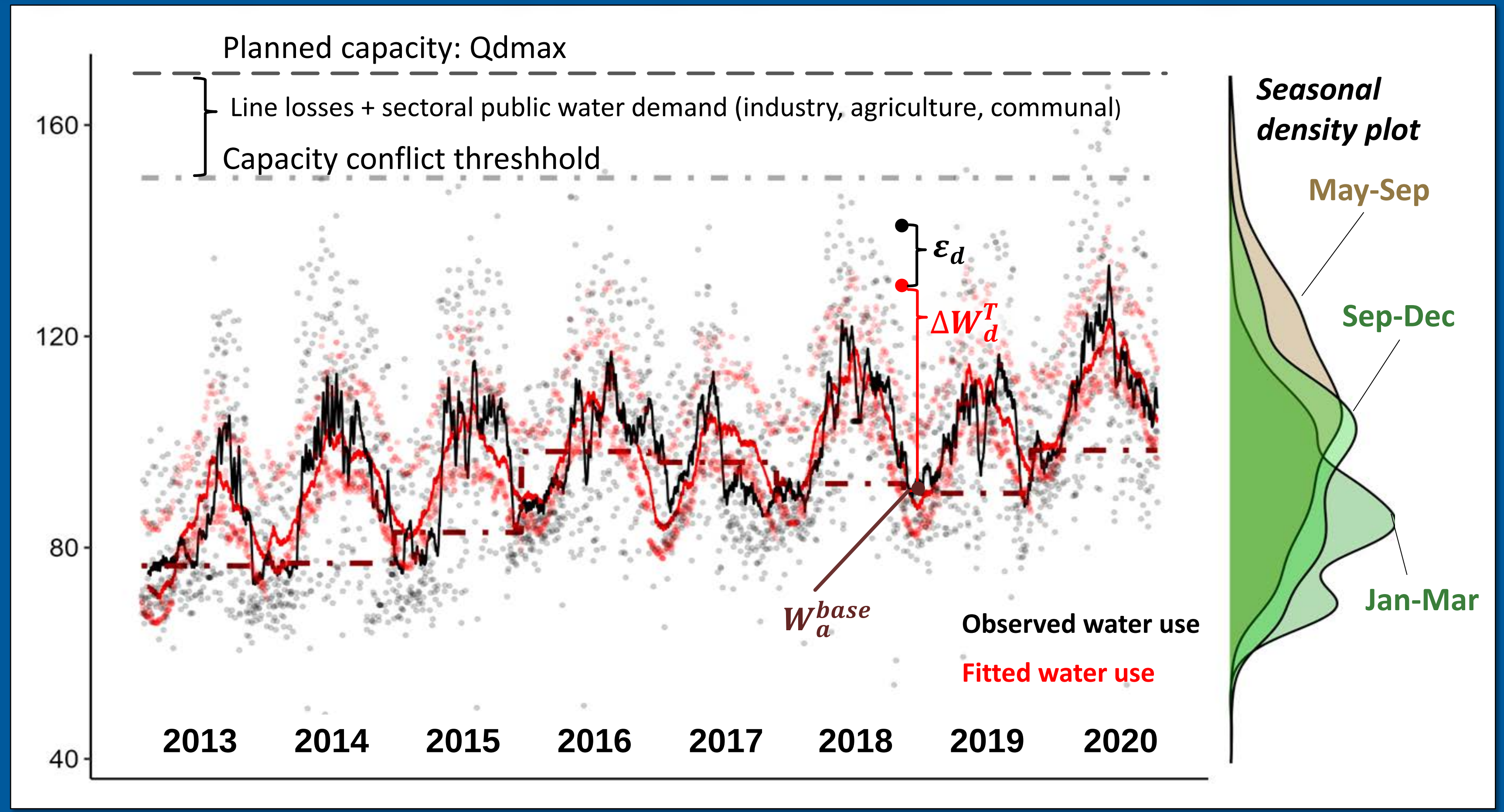


Figure 3: Daily water discharge per capita [liter/day] „Hochbehälter Effelder"



Source: Sample region „Hochbehälter Effelder" from water supplier „Wasserwerke Sonneberg". Points depict daily data points and lines depict thirty day moving averages.

Table 1: Parametrization results: Multivariate OLS regression analysis

	Seasonal model: $y = W_d^T$; $y = \Delta W_d^T$				Base model: $y = \ln(W_t^{T\ base})$		
	No BWU	*BWU ($T_d^{max} < 0$)*	*BWU & autocorr. term*		*No pooling*	*Supply area fixed effects*	*Year fixed effects*
(Intercept)	105,89***	4,21*	-15,30***	(Intercept)	1,18***		
TXK0	0,74***	0,44***	0,33***	av_pr	-0,12***	0,04	-0,12***
TXK25	0,77***	0,56***	0,44***	ln_av_inc	0,36***	0,36***	-0,10
ln_SWC	-3,94***	-1,25***	-0,86**				
we_dum	13,80***	13,85***	12.74***				
auto_co			0,17**				
fak1, fbk1, fak2, fbk2	1,61*, -2,08***, 0,23, -1,50***	-2,70***, -3,15***, 0,21, -1,27***	1,15***, -1,31**, 0,24, -1,15***				
Residual standard error	16.,46	13,64	13,2	*Panel*	Unbalanced Panel: n = 29, T = 1-7, N = 140	Unbalanced Panel: n = 29, T = 1-7, N = 140	Unbalanced Panel: n = 7, T = 12-24, N = 140
Degree freedom	4327	4320	4324				
(Multiple) R-squared	0,29	0,51	0,39	*R-squared*	0.16949	0.10051	

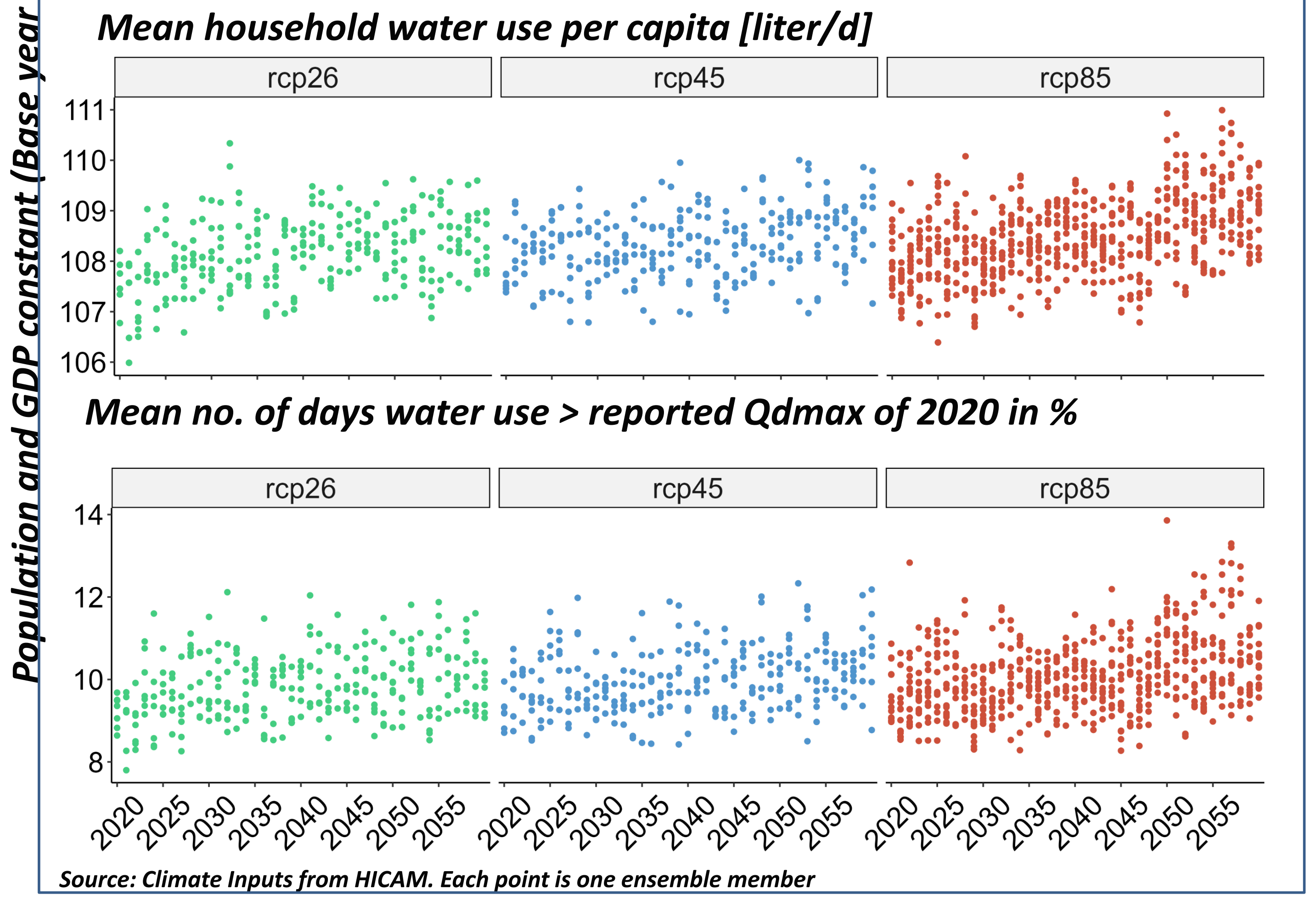
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Scenario Results

Reference developments of socio-economic and climatic drivers are represented by combinations of **Regionalized Concentration Pathways (RCPs)** and regionalized **Shared Socio-economic Pathways (SSPs)** for the period **2020-2060** to address **uncertainties**.

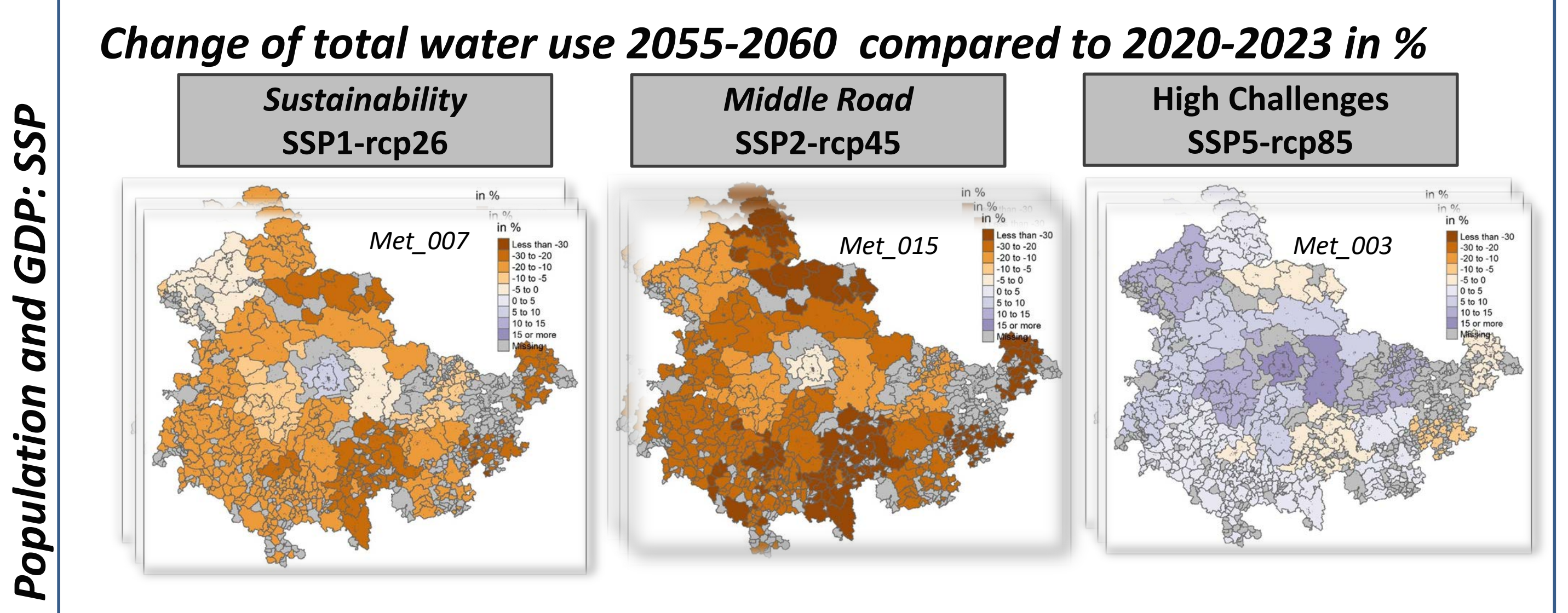
- ***RCP***: 1km grid HI-CAM-Ensemble(Jacob et al., 2014, Hübner et al. 2017) driving mHM (Samaniego et al. 2010, Kumar 2013 et al. , Thober 2019 et al.) for temperature and soil moisture.
- ***SSP***: GDP and population from the SSP database. Regional population projections (DESTATIS) scaled to SSP population drivers (KC & Lutz 2016).

Climate change can increase water demand and use conflicts



Source: Climate Inputs from HICAM. Each point is one ensemble member

Socio-demographic change is the main driver



Water demand patterns are regionally heterogenous

Take Home

- A **spatially disaggregated** model of household water demand allows to identify future **regional water use conflicts**
- We find that **temporal patterns** of household water demand are **weather dependent** and that water demand **increases** under **strong climate change**
- An implementation **of econometric base water use** can inform socio-economic impacts of **demand management** in different socio-climatic futures