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Synergistic nature of sustainable development solutions centred on heat stress in the urban system

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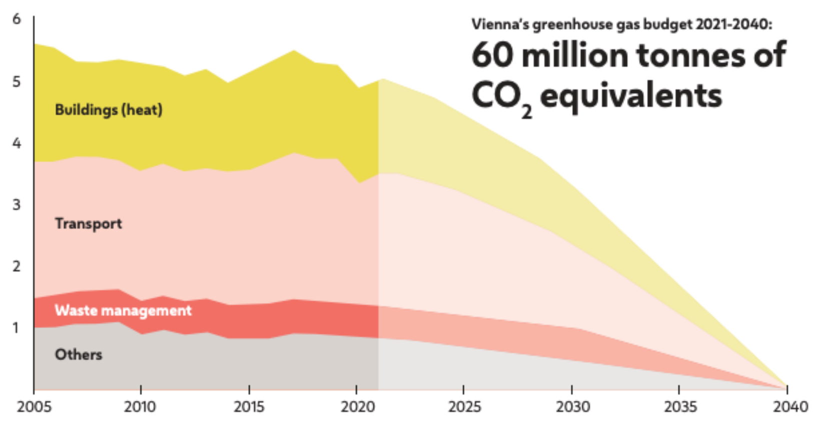


Figure 1 Total greenhouse gas emissions in Vienna by sectors in million tonnes of CO2-EQ/year[1] (in: Phasing Out Gas – Heating and Coolihng Vienna 2040). While ambitious goals are fixed, reality hardly changes either.

Extreme weather events are increasing, forcing city governments to implement measures to mitigate their impacts. Active measures can mitigate heat stress and flood risk, and synergize with emission targets (see Fig. 1) and other sustainable development goals. The study is based on Imp_DroP project results and stakeholder discussions and focuses on Vienna, Austria during drought and heat waves. A number of potential synergies can be identified (Fig. 2). Important levers for both reduction in local temperatures and a decrease in the city's contribution to greenhouse gas emissions are change in radiation control (e.g. higher reflectivity, use of solar energy for electricity, retrofitting buildings, shade via window shutters and/or trees) and increasing evapotranspiration (e.g. green roofs, street trees, low level vegetation, irrigation). Effects of selected solutions as simulated using the TEB model within SURFEX v9 [2,3,4] for local (Fig. 3) and city scale (Fig. 4) heat stress. Further transition to mobility as a service (MaaS) and electrifciation reduces heat emissions.

Potential synergies

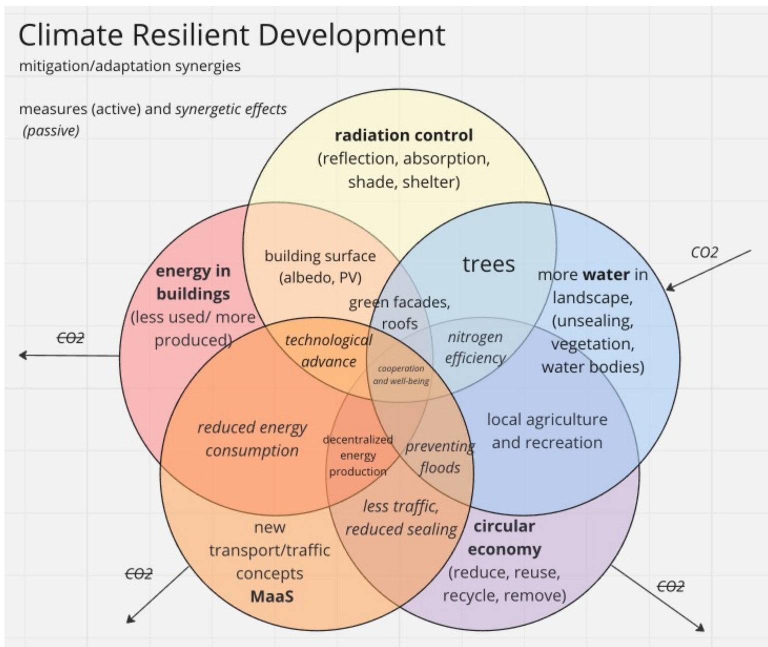


Figure 2 Potential synergies between different solutions.

Local heat stress solutions

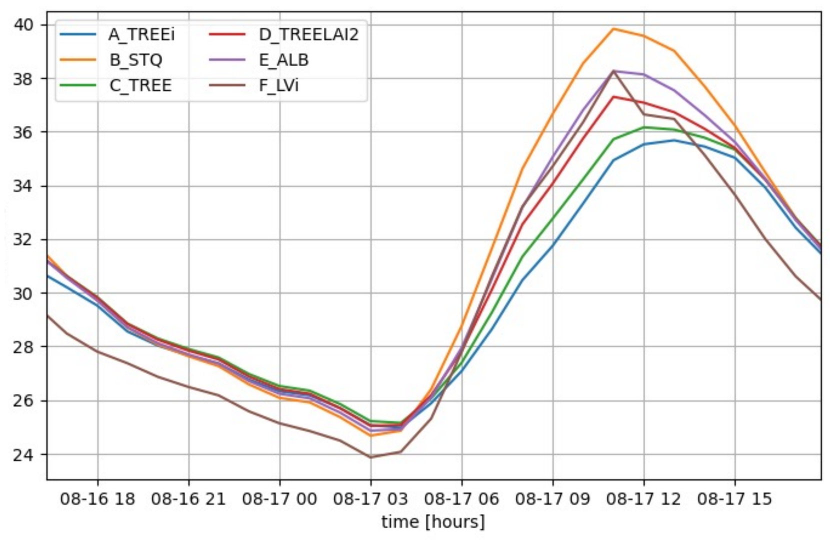


Figure 3 Reduction of Universal Thermal Comfort index (UTCI) in the street canyon compared to STQ (no measure) (TREE[i] = [irrigated] dense trees, TREELAI2 = light trees, ALB = roof reflectivity increased to 0.6, Lvi = irrigated low vegetation in the street canyon).

City scale heat stress sol.

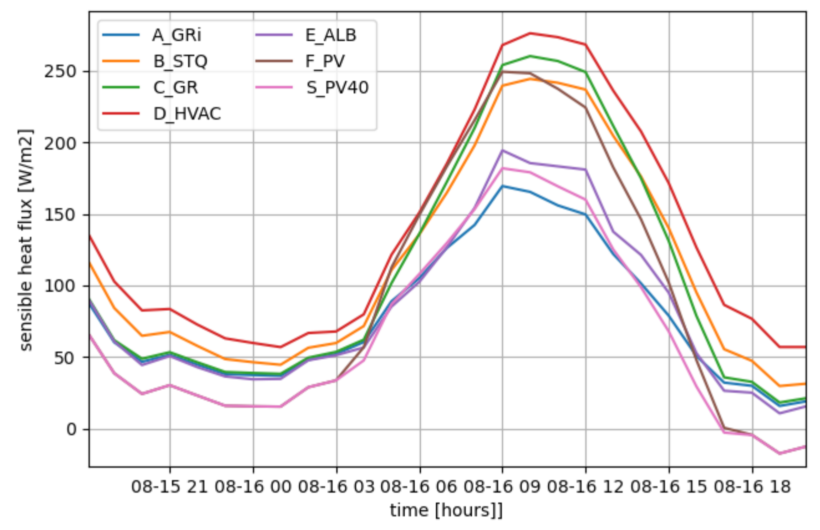
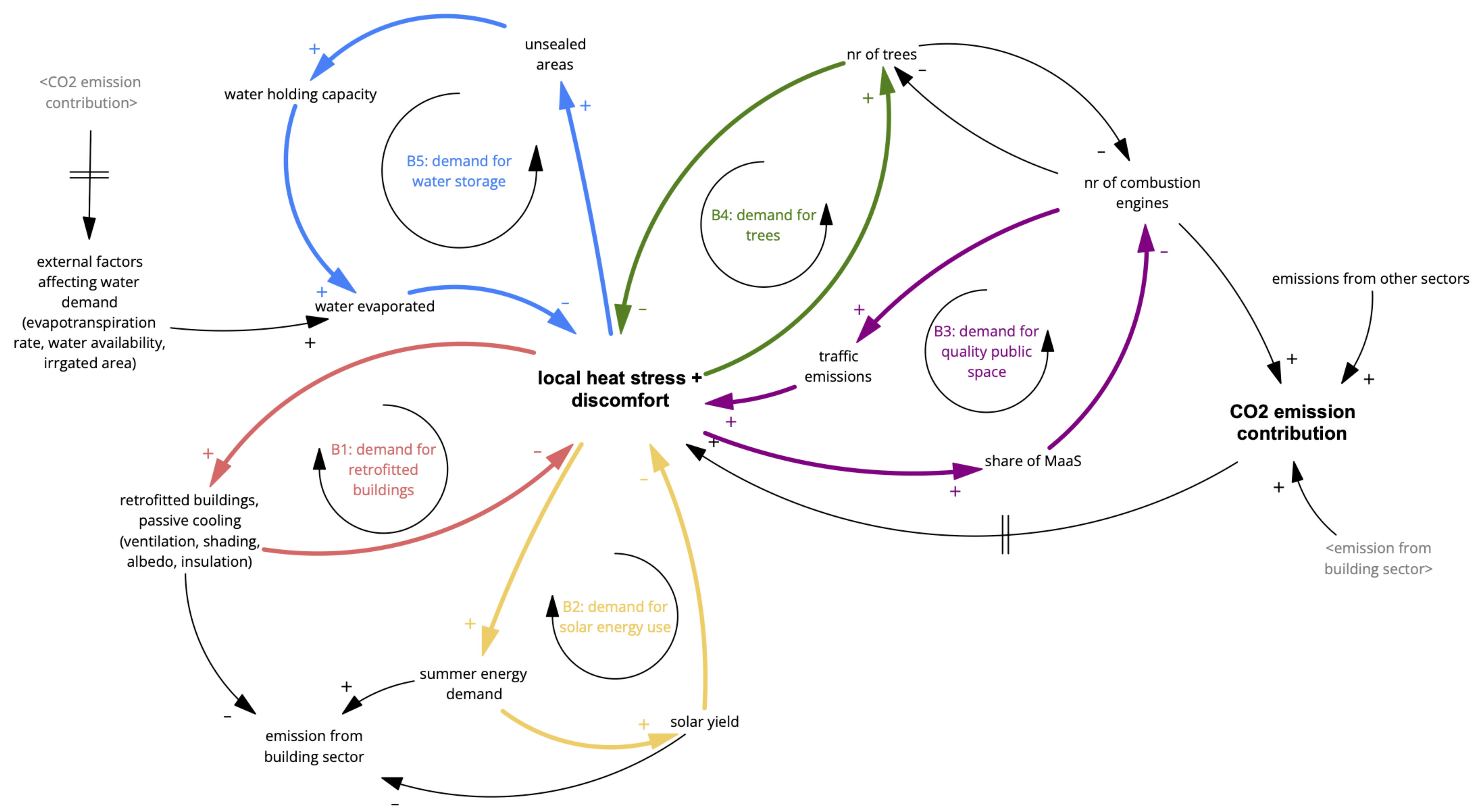


Figure 4 Influence of sustainable development solutions on sensible heat flux above roof level (GR[i] = [irrigated] green roof, ALB = root albedo increased to 0.6, PV = solar panels, PV40 = solar panels efficiency 0.4, HVAC = heating ventilation and cooling system on).

Figure 5. Causal loop diagram illustrating the dynamic hypothesis for urban development solutions (highlighted in color with bold arrows) aimed at countering drought and heat stress in Vienna. The remaining feedback loops, shown in black, represent key interactions that emerge when these solutions are implemented, such as spatial trade-offs and shifts in climate risk perception. B = balancing, R = Reinforcing, + = positive causal link, - = negative causal link. Double-hashed arrow = time delay.



The implementation of these solutions is shaped by various reinforcing and balancing dynamics. Feedback loops are used to visualize these interactions and to identify critical areas for better decision-making and policy integration. We present a dynamic hypothesis map of the overall system to illustrate the full range of interactions and dependencies (Fig. 5).

Given the limited availability of urban space, there is increasing competition for public areas at the pedestrian level (Fig. 6) as well as for rooftop space (Fig. 7). These spatial dynamics interact with other measures aimed at enhancing local climate adaptation and reducing CO_2 emissions (Fig. 8). The collective impact of these actions (B1 to B5 in Fig. 5) can reduce risk perception and consequent engagement in global CO2 contribution.

Conclusions: A feedback perspective that considers the broader system can help identify competing objectives and long-term barriers in sustainably mitigating heat stress.

Dethroning car dominance

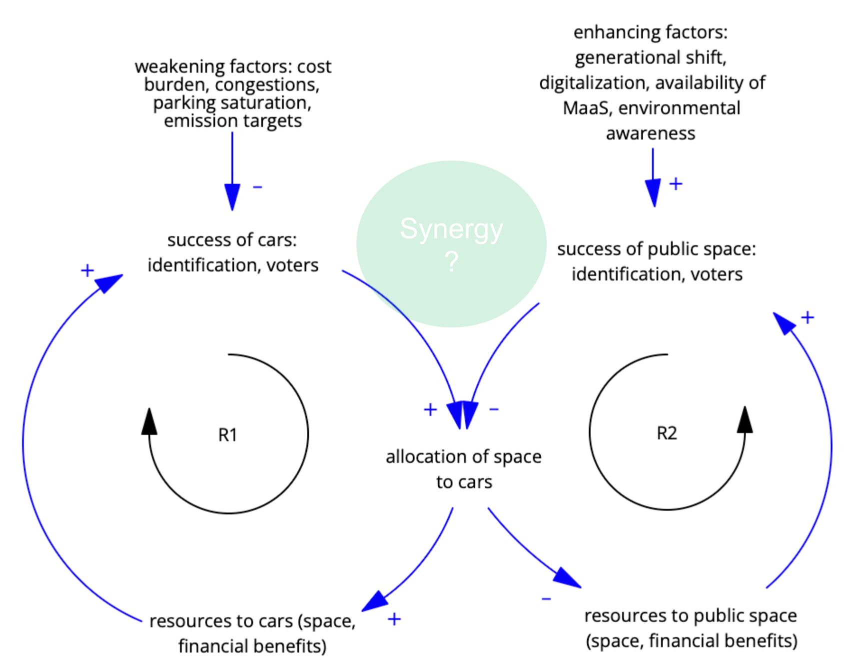


Figure 6 The competition between cars (R1) and the public realm (R2) for space reflects the historic *Success to the Successful* archetype, though this dynamic is now weakening. Strong outcomes on both sides could promote research into potential synergies.

Arms race for roof area

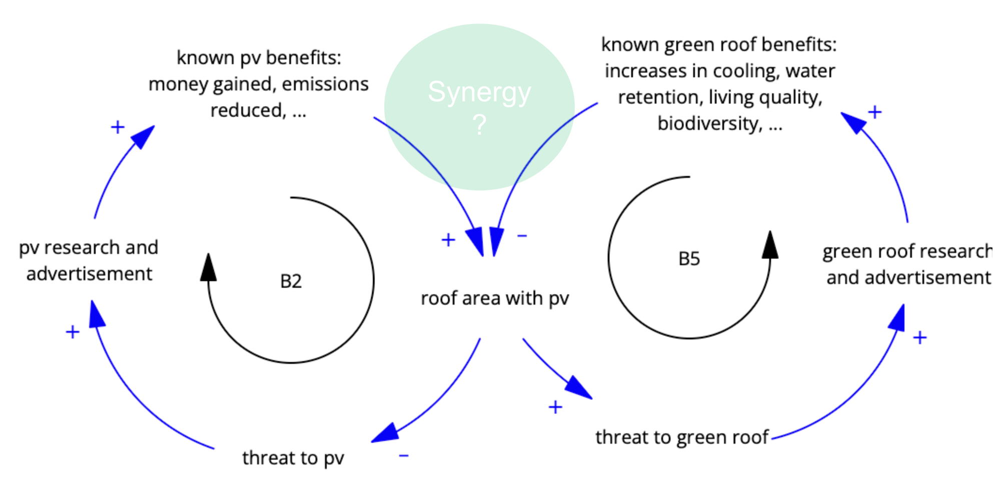


Figure 7 The competition between photovolatic (B2) and green roofs (B5) communities for roof area can be seen as *Escalation* archetype. This dynamic pushes to find synergies.

Reducing discomfort reduces risk perception

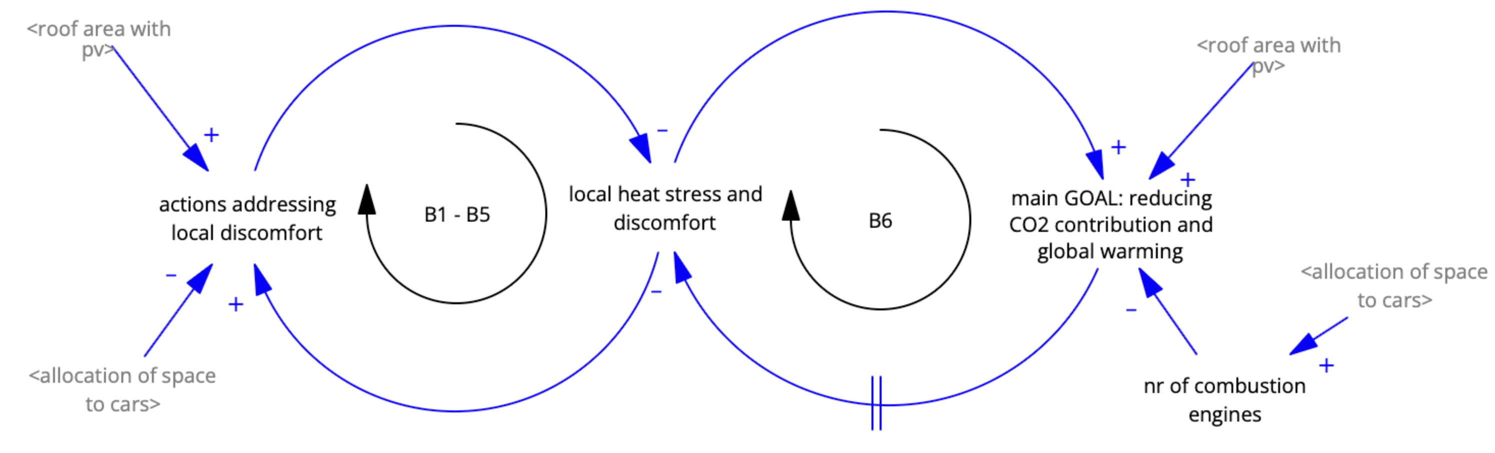


Figure 8 Mitigation adaptation dynamic, which runs into danger of the *Eroding goals* archtype. Extreme events especially heat waves increase climate risk perception and can act as important lever for phasing out gas investments. When local adaptation (B1 - B5) is very effective and extreme events are not felt as alarming (B6), this lever looses might.

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