



# Scenario-Based Identification of Critical Thresholds in Interdependent Urban Water–Energy Systems under Climate Extremes

— A Typology-Based Comparison of Seoul Districts

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## I. Research Motivation

## II. Methods

## III. Results

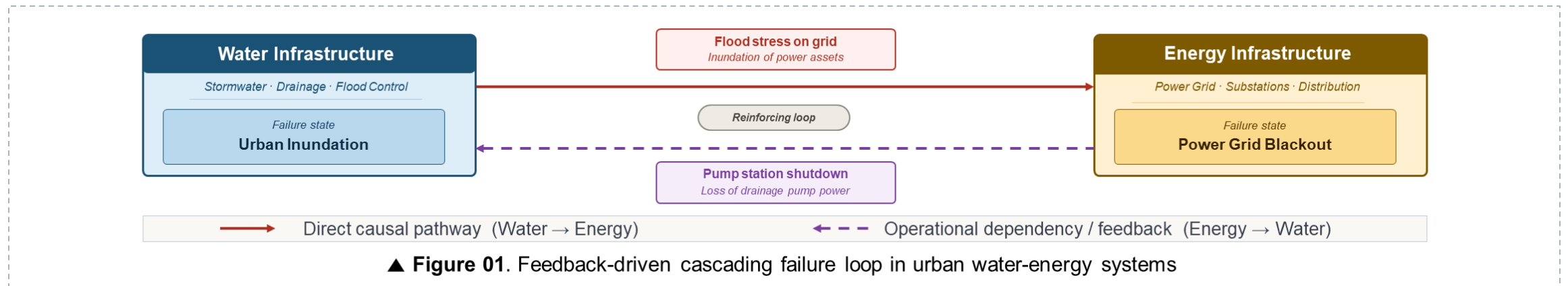
## IV. Key Implication



# I. Research Motivation

# A. Research Background

- Interdependent drainage and power systems face rapid failures under intensifying climate extremes.
- Sustained climate stress triggers abrupt system collapse beyond critical thresholds.
- Varying district-level resilience in Seoul necessitates a typology-based comparative framework.



## B. Research Questions

This study addresses these gaps through a scenario-based, typology-driven analysis of interdependent urban Water–Energy systems in Seoul.

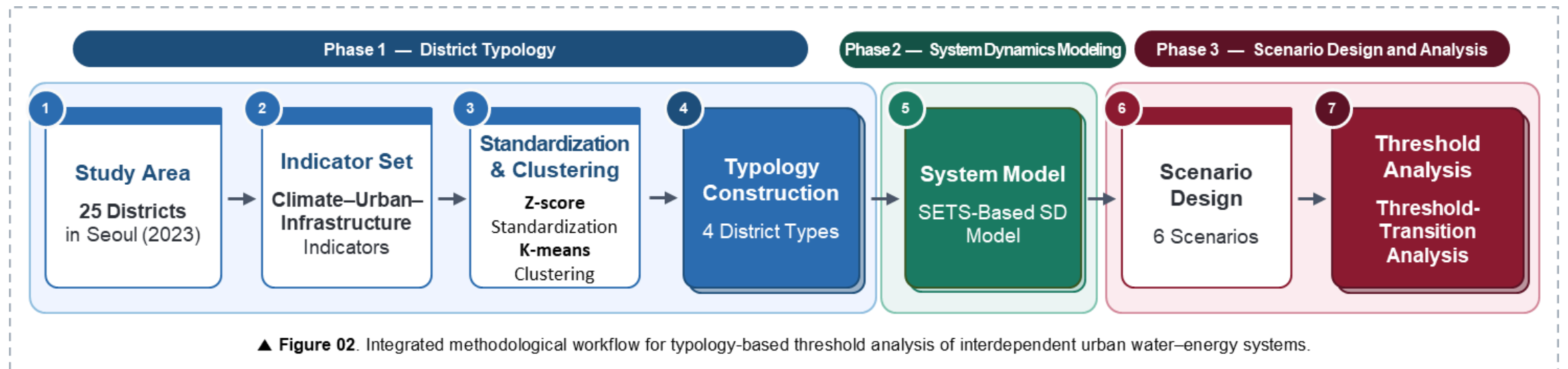
- 1) To what extent do district-level differences in climate exposure, urban form, and infrastructure capacity explain compound infrastructure vulnerability in Seoul?
- 2) How does water–energy infrastructure interdependency influence system stress accumulation under climate extremes?
- 3) How do threshold-transition dynamics vary across district types under alternative climate and infrastructure scenarios?



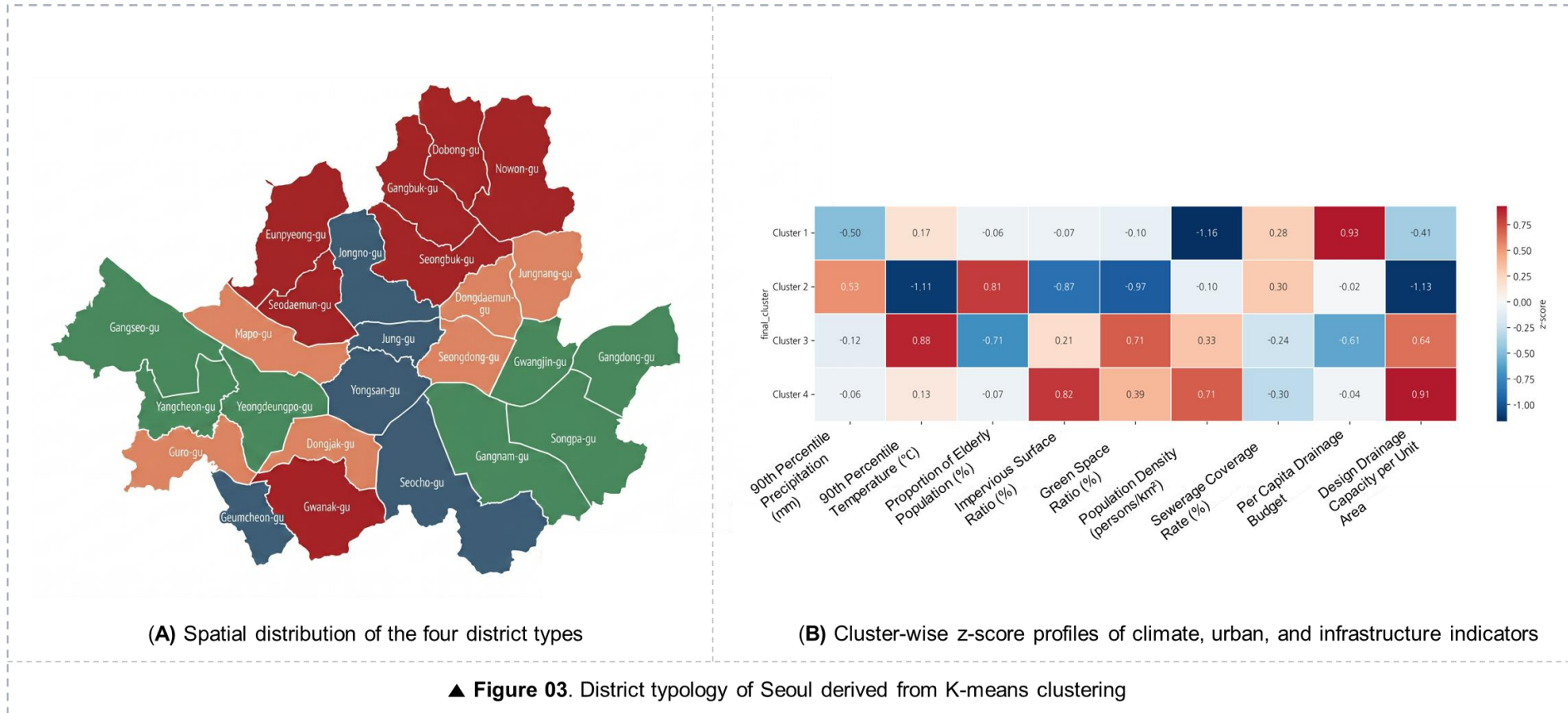
## II. Methods

# A. Analytical Scope

- **Study Area & Typology** : Seoul (25 districts), classified by exposure and infrastructure capacity
- **Method** : Typology-based spatial clustering and System Dynamics modeling
- **Focus** : Water–energy interdependency and threshold-transition dynamics
- **Scenarios** : Climate shock, infrastructure degradation, and intervention timing



## B. Clustering Results: Urban Resilience Typology



**Type 1**

Infrastructure-intensive urban core — high capacity, event-sensitive stress spikes

**Type 2**

Climate-vulnerable, low-capacity districts — persistent stress accumulation

**Type 3**

Heat-exposed, activity-intensive districts — concentrated nonlinear damage (May–Aug)

**Type 4**

Mixed-structure transitional districts — conditional threshold approach

## C. Interdependent System Framework

### 1) SETS-based (Socio-Environmental-Technical Systems) System Dynamics modeling

- Objective: Simulating interactions between urban flooding & energy service disruptions
- Key Mechanisms: Tracing stress accumulation, recovery delays, and cascading effects under climate extremes

### 2) Core Variable Groups

- Water System: Flood occurrence, infiltration capacity, net runoff, drainage load, recovery time
- Energy System: Energy service loss, thermal stress, grid load stress, outage duration
- Threshold Response: System stress index, recovery delay, nonlinear damage growth, threshold state



## E. Scenario Design

### Baseline

#### 2023 reference conditions

- Average climate and infrastructure performance

### Climate Shock

#### Rainfall intensity $\times 2$ & heatwave rate $\times 2$

- Isolates climate forcing

### Infrastructure Degradation

#### Drain capacity $-40\%$ & sewer density $-20\%$ & recovery capacity $-40\%$

- Tests infrastructure fragility

### High-Interdependency

#### Recovery capacity $-40\%$ & backup power $-20\%$

- Tests interdependency as a risk amplifier

### Worst Case

#### Climate shock + Infrastructure Degradation + High-Interdependency

- Combined maximum-stress condition

### Pre-emptive Policy

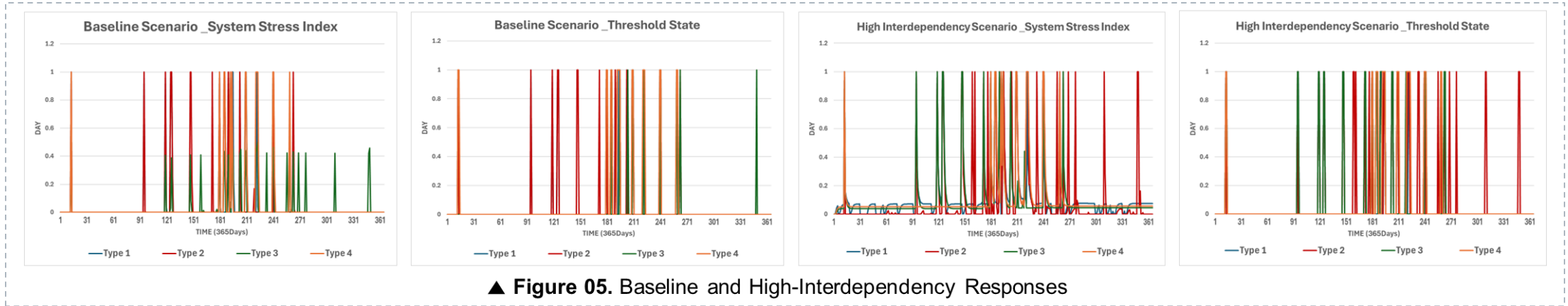
#### Worst-case condition with Early / Near / Late intervention

- Compares intervention timing



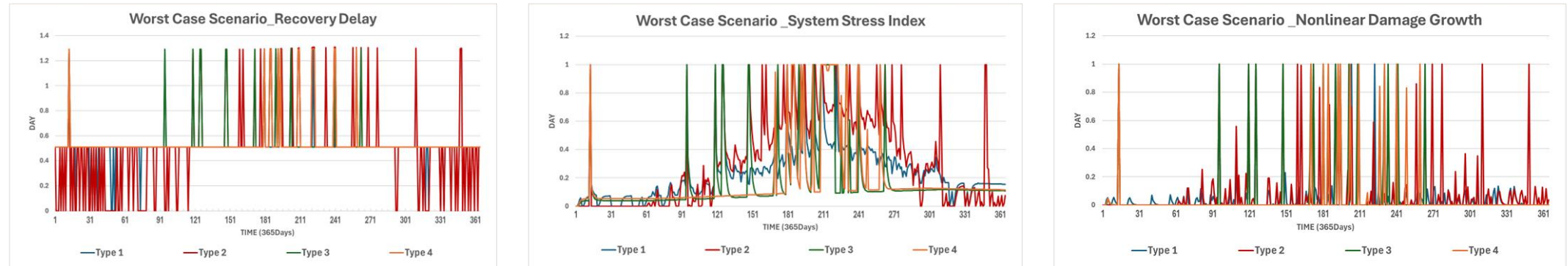
## III. Results

# A. Baseline and High-Interdependency Response (Scenario : Baseline & High Interdependency)



- **Type 1** maintained relatively strong baseline performance, but exhibited short-term stress spikes under stronger interdependency.
- **Type 2** showed the most persistent stress accumulation and prolonged threshold conditions, reflecting structurally weak infrastructure capacity.
- **Type 3** showed concentrated nonlinear response under intensified system coupling.
- **Type 4** remained moderately stable under baseline conditions, but approached threshold states rapidly under stronger interdependency.

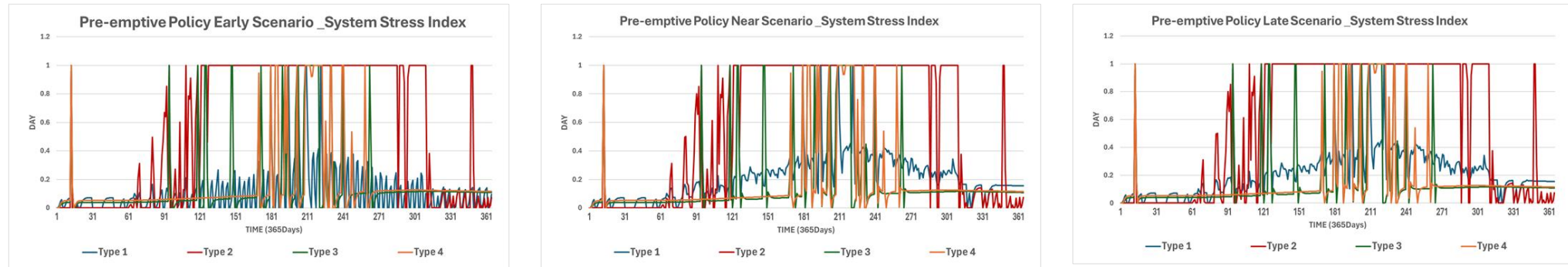
## B. Escalation under Compound Stress (Scenario : Worst Case)



▲ Figure 06. District-type threshold responses under compounded stress conditions

- Under compounded stress, threshold responses became both stronger and more persistent across district types.
- **Type 2** showed the clearest pattern of prolonged recovery delay and persistent system stress.
- **Type 3** showed the strongest concentration of stress under highly coupled and climate-sensitive conditions.
- **Worst-case** produced the most severe threshold transitions across the full district typology.

## C. Effects of Intervention Timing (Scenario : Pre-emptive Policy)



▲ Figure 07. Effects of intervention timing on threshold duration and system stabilization

- **Early intervention** produced the strongest stabilization effect by reducing threshold duration and limiting stress concentration.
- **Near intervention** produced only partial improvement once stress had already accumulated.
- **Late intervention** showed limited benefit after the system had already approached critical thresholds.



## **IV. Key Implication**

## A. Key Implication

- Threshold-transition dynamics vary systematically across district types in Seoul.
- Urban climate risk is amplified through water–energy interdependency.
- Early, typology-based intervention offers the clearest pathway to stabilization.
- Adaptation planning should move beyond one-size-fits-all strategies toward district-specific and interdependency-aware decision making.

### **Key Message:**

*As climate extremes intensify, urban adaptation strategies should prioritize climate-vulnerable district types where insufficient infrastructure capacity and strong water–energy interdependency jointly increase the likelihood of threshold transitions.*

# Thank you.

- Question?

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