

National Technical
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Spatial Indicators of Dynamic Self-Sufficiency and Resilience in the Water–Energy–Food Nexus Case study: Small Rural Village in North Euboea, Greece

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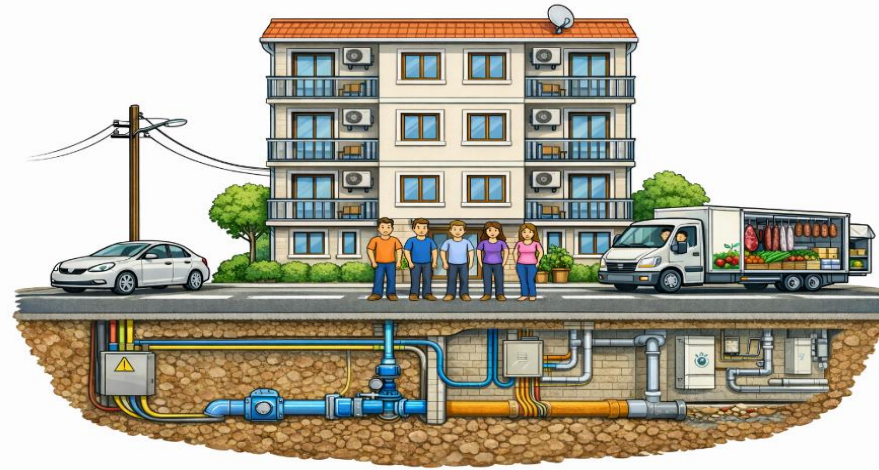


Introduction

- The proposed framework conceptualizes self-sufficiency and resilience in the Water–Energy–Food (WEF) Nexus as emergent properties of physically constrained resource systems. Rather than treating water, energy, and food as independent or symmetrically interacting sectors, the framework adopts a modular and hierarchical structure that reflects the underlying causal relationships between resource flows, infrastructure, and spatial organization
- All indicators are defined on a per-capita basis, allowing direct comparison across different spatial scales, population densities, and settlement types. Depending on data availability and analytical needs, indicators can be aggregated at the level of households, settlements, or larger regions. Within this framework, resilience is interpreted as the capacity of a system to maintain the provision of essential services under conditions of resource scarcity, infrastructural disruption, or external shocks, without assuming unlimited access to distant or imported resources.



Concept of the indicators



Structure of the indicators

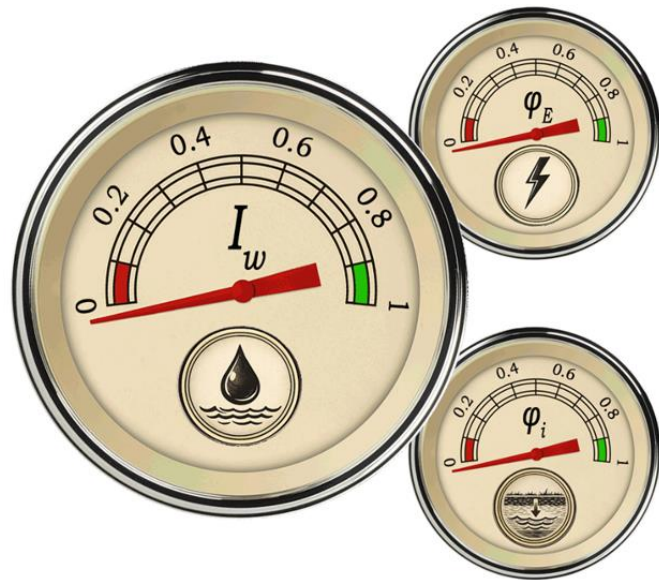
- The system's capacity is ultimately limited by its weakest component, and high performance in one sector cannot compensate for critical deficiencies in another.
- The Water–Energy–Food (WEF) relationship is not treated as a symmetric or circular interaction, but rather as a hierarchically structured system of constraints.

The underlying logic is as follows:

- Water self-sufficiency depends on energy availability, due to the energy requirements associated with abstraction, pumping, transport or desalination.
- Food self-sufficiency depends on both water and energy, through irrigation requirements, fertilizer production, fuel use, and transport.
- Energy self-sufficiency does not directly depend on water or food, unless explicitly defined through biomass-based pathways.

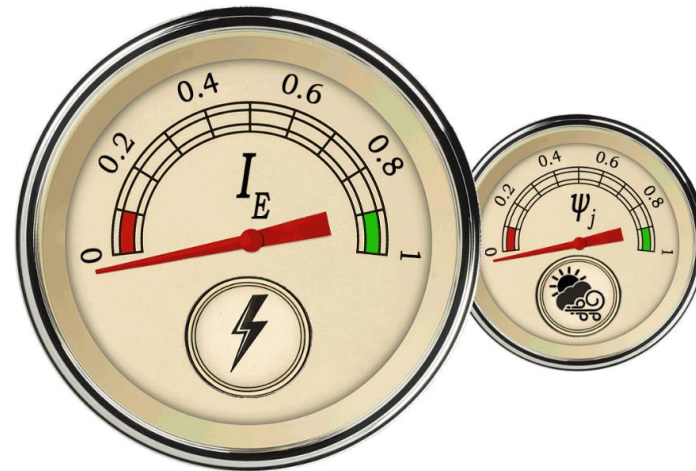
Water

Water demand is defined as the minimum per-capita volume required to sustain hygienic living conditions and enable local food production under resource-constrained conditions.



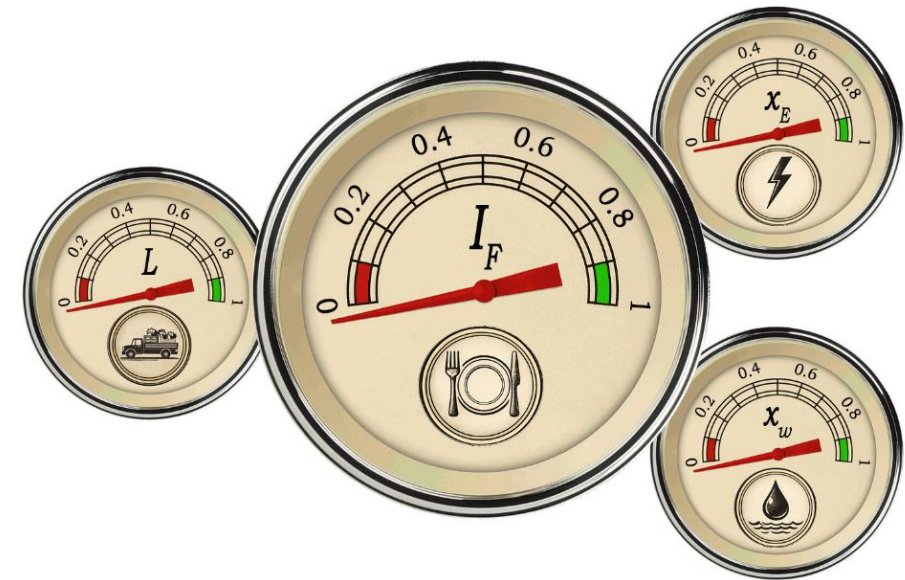
Energy

1. Household electricity demand
2. Space heating demand
3. Space cooling demand
4. Transportation energy demand
5. Energy embedded in food production



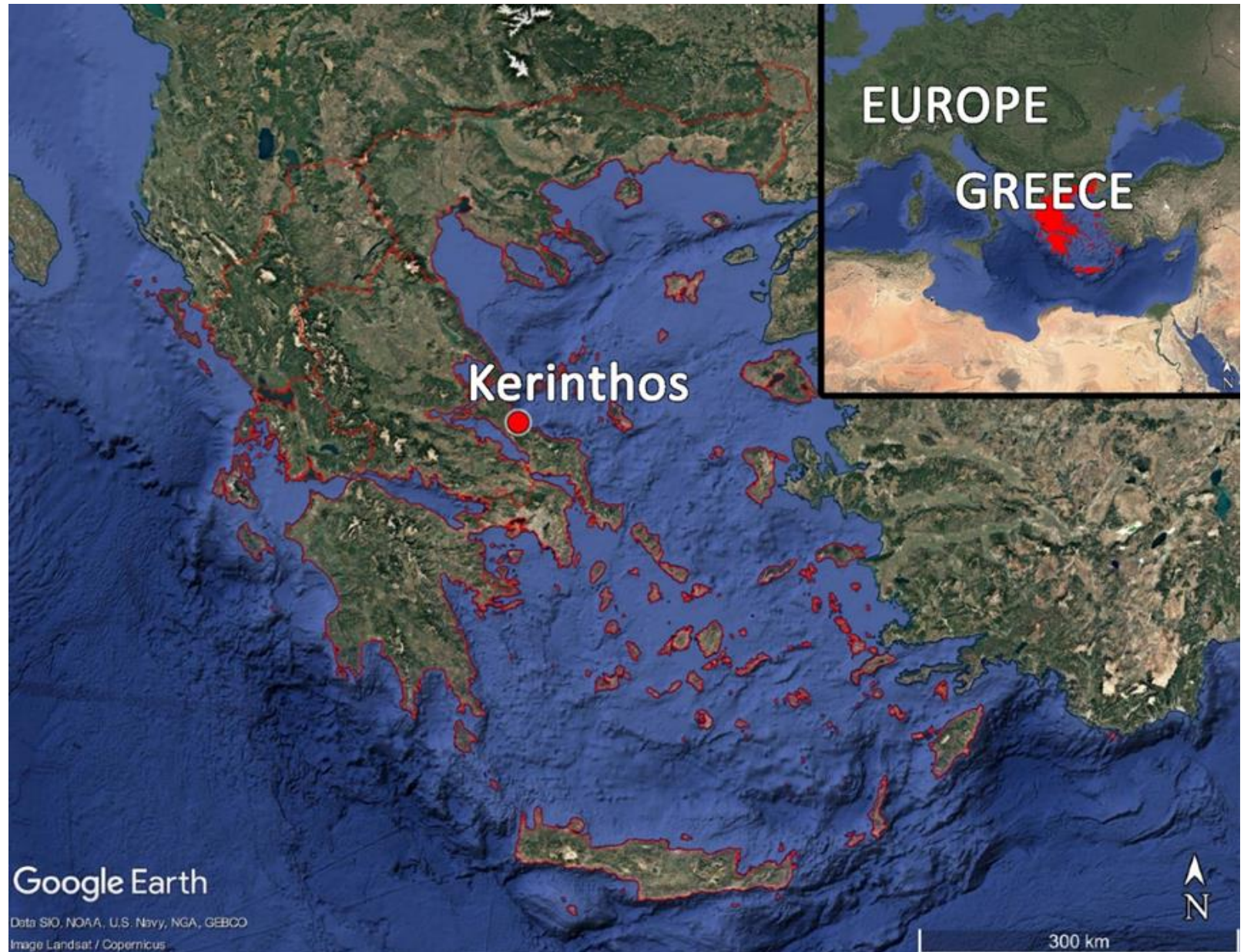
Food

Food self-sufficiency is defined as the degree to which the per-capita food demand, expressed as agricultural land requirement, can be met through locally available production systems.



Case study area

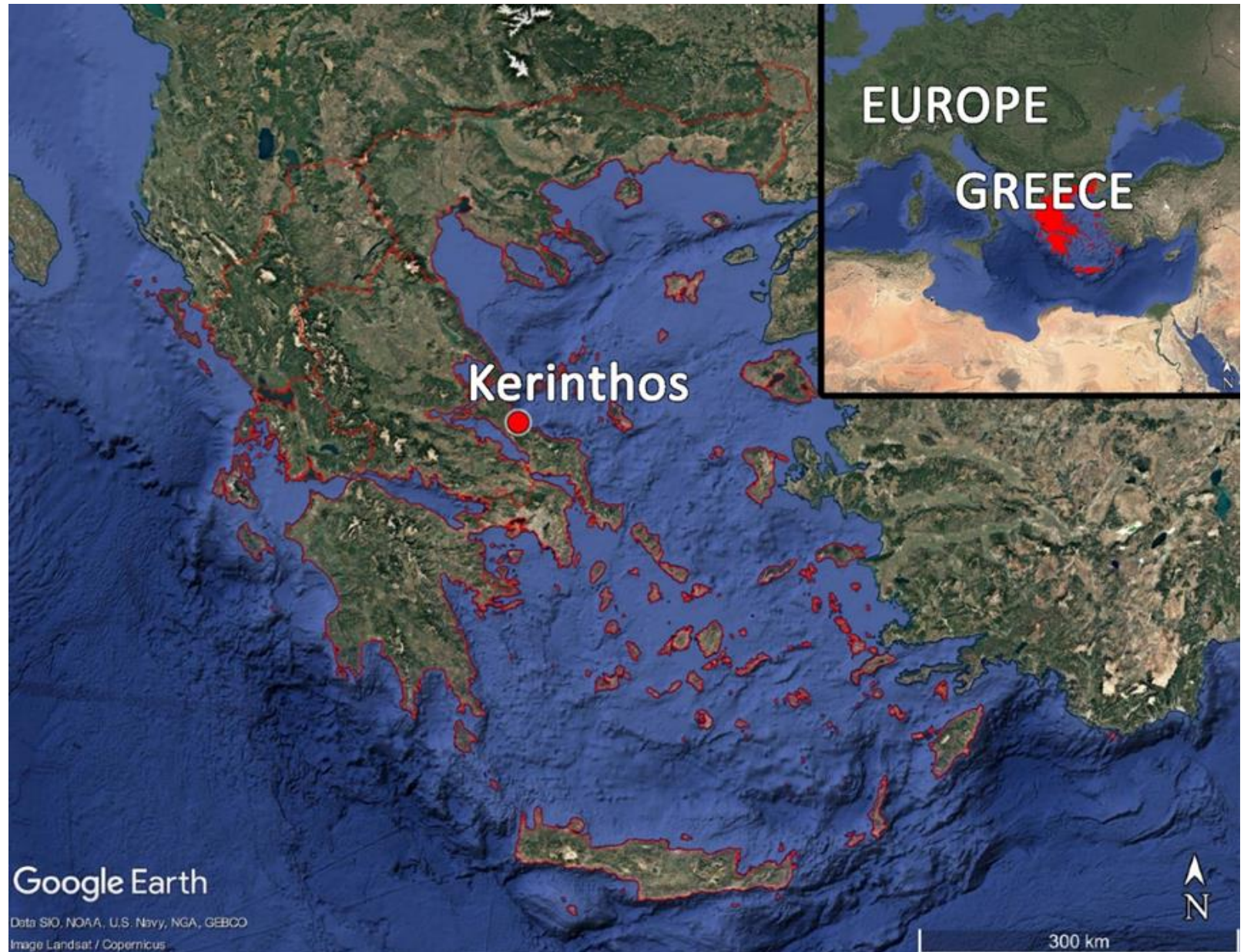
North Euboea is a region with pronounced exposure to climatic variability, seasonal water stress, and ecological disturbance, most notably following large-scale wildfires in recent years. At the same time, the area exhibits substantial availability of natural resources, including surface water, groundwater, agricultural land, forests, and renewable energy potential. This combination of resource abundance and infrastructural vulnerability makes the region particularly suitable for resilience-oriented assessment within the Water–Energy–Food (WEF) Nexus.



Case study area

The proposed framework is applied to the rural village of Kerinthos, located in North Euboea, Greece, as a proof-of-concept case study.

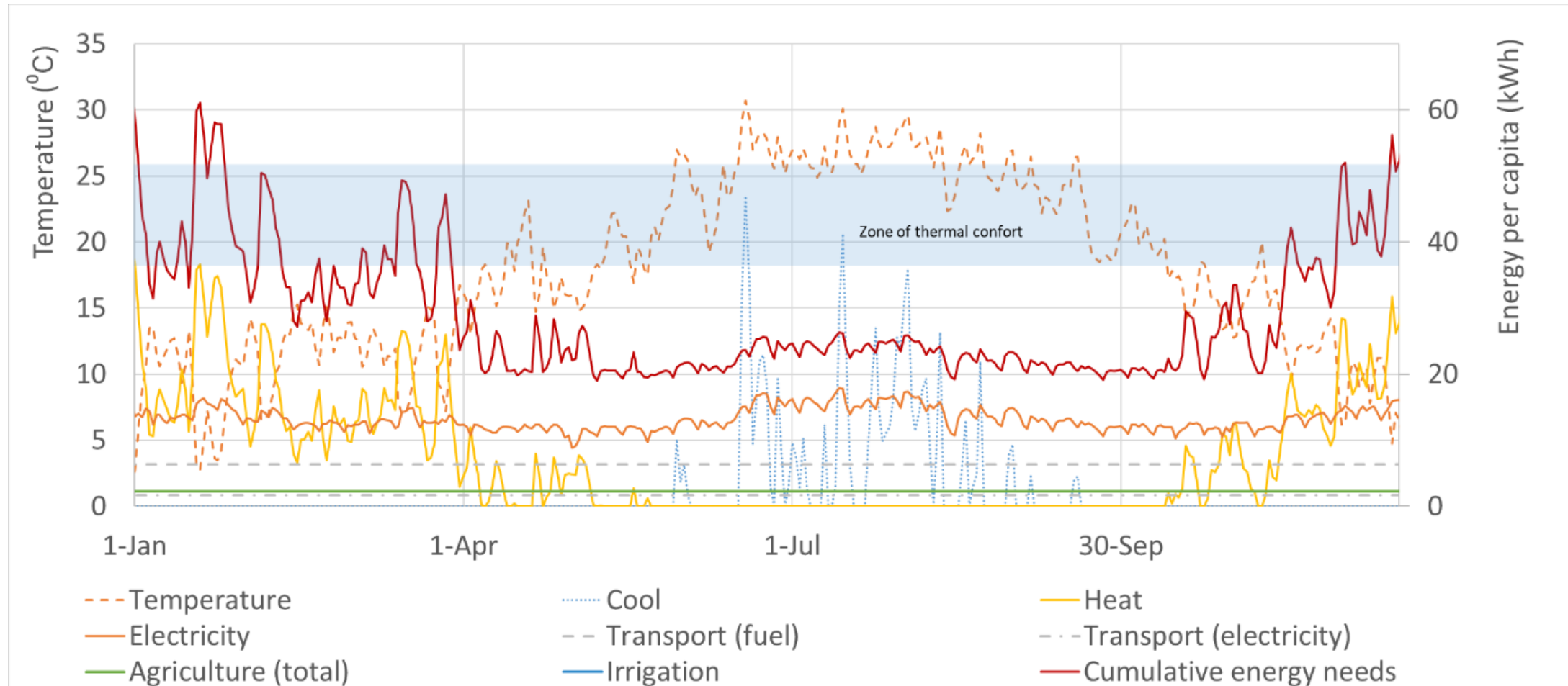
Kerinthos is a small settlement with a permanent population of approximately 600 inhabitants and is representative of many rural Mediterranean communities characterized by low population density, mixed land uses, and partial dependence on centralized infrastructure systems.



Case study area

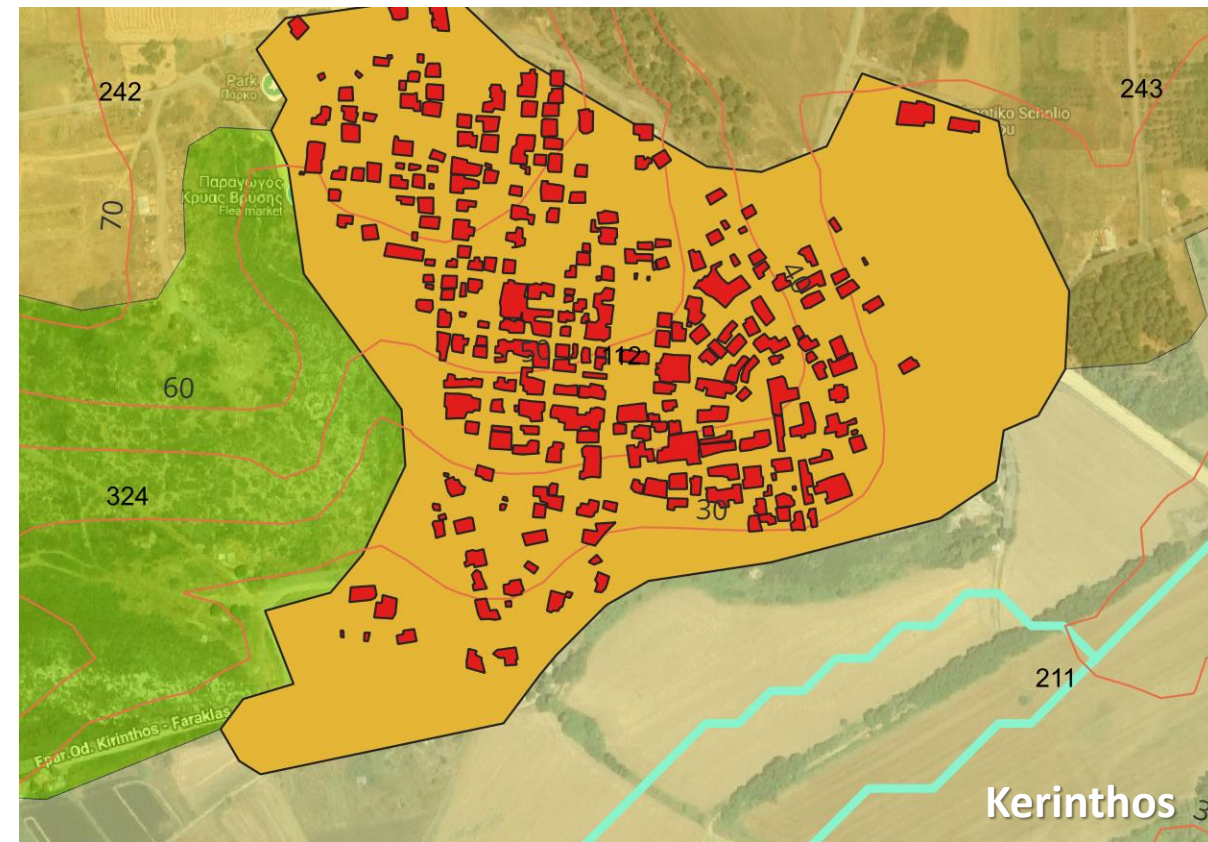
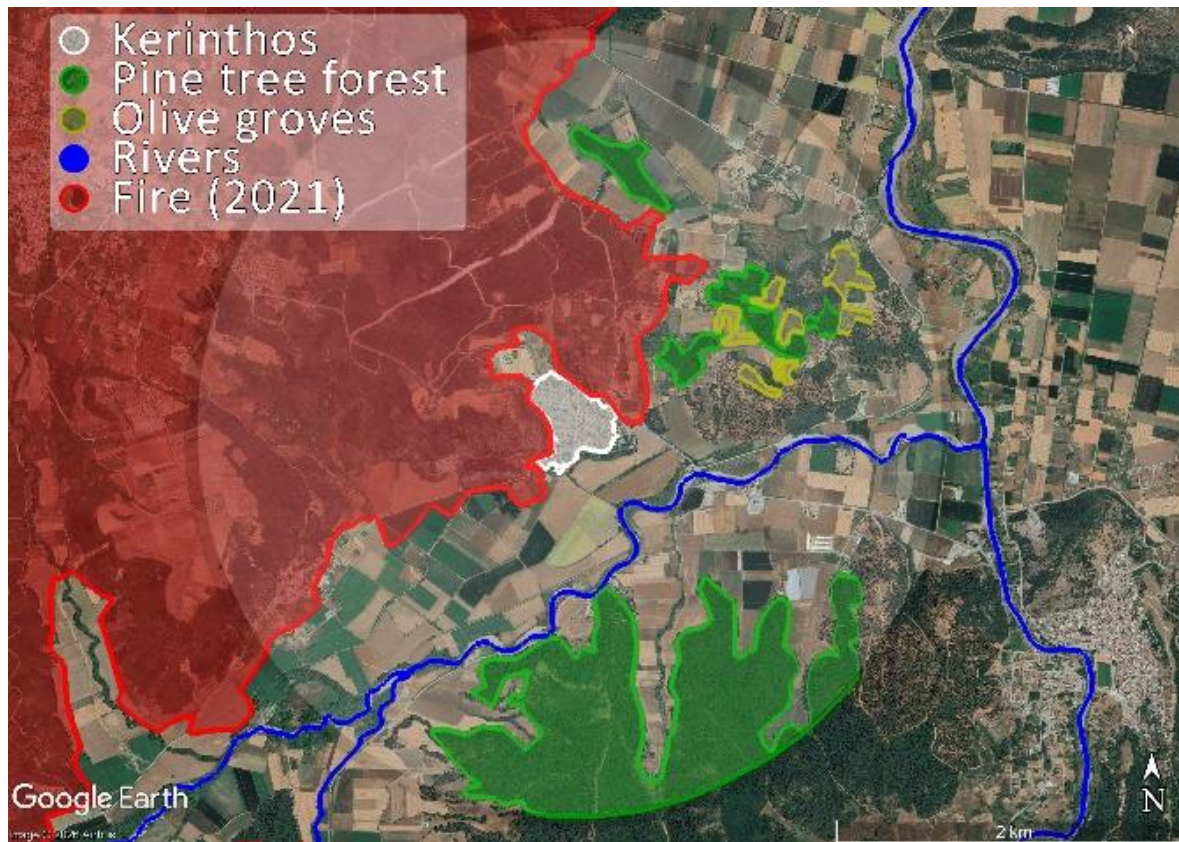


Energy needs per capita



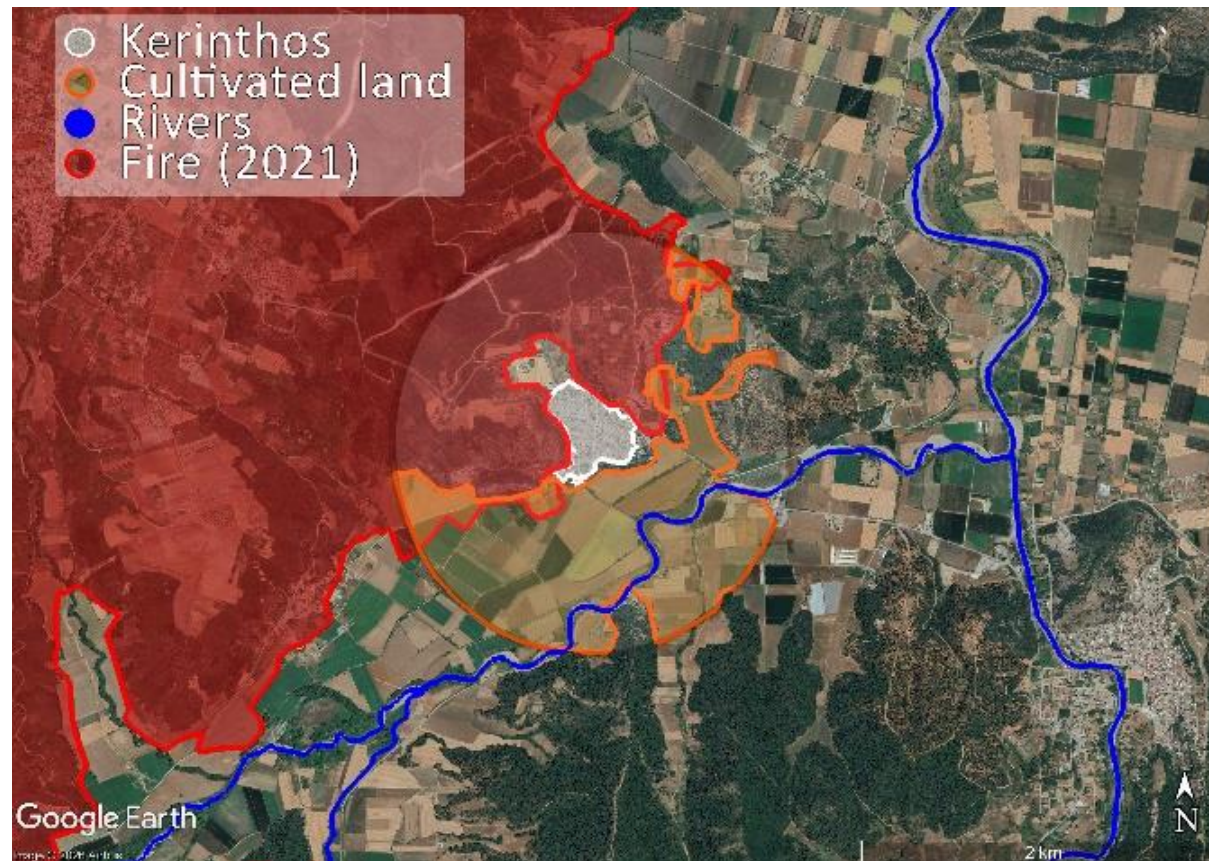
Land use for energy needs

Under baseline conditions, the energy system serving the settlement of Kerinthos in North Euboea, Greece, is characterized by strong dependence on external energy inputs. Electricity is imported through the national grid, transportation relies predominantly on fossil fuels, and agricultural production depends on externally supplied fuels and fertilizers. Space heating constitutes a notable exception, as it is largely covered by locally available biomass from surrounding forests and olive groves.



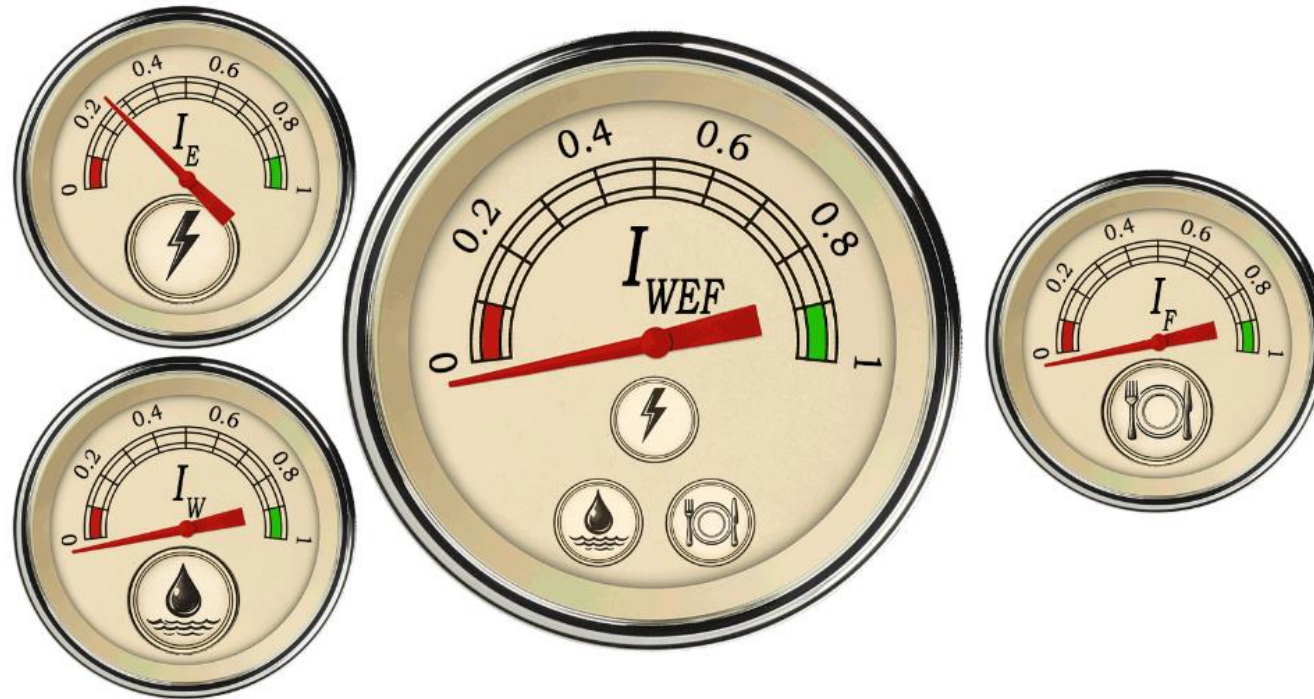
Land use for food needs

Under baseline conditions, food demand for the settlement of Kerinthos in North Euboea, Greece, can be met in volumetric terms through locally available agricultural land which proximity is in average 500 m to the settlement to satisfy the adopted threshold of 0.2 ha per capita, indicating that land availability alone does not constitute a limiting factor.



Evaluating present status of WEF nexus

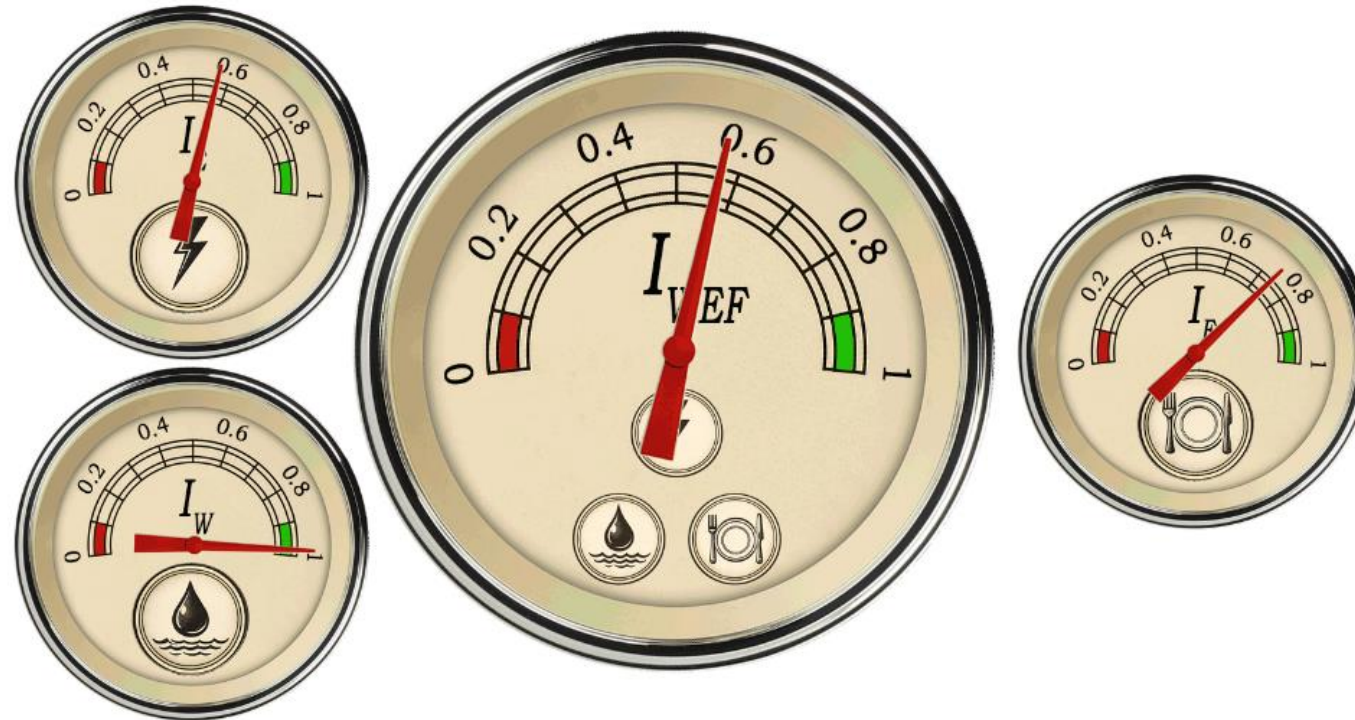
Despite the presence of abundant natural resources, the WEF Nexus in its current configuration is functionally non-resilient. Dependence on external energy inputs propagates through the system, rendering both water and food provision vulnerable under conditions of disruption. In resilience terms, the system cannot sustain its core functions without continuous external support.



Optimization of WEF nexus

In the optimized scenario where surface water replaces groundwater abstraction and renewable electricity is introduced without storage, the constrained indicators improve substantially.

This result represents a transition from a non-functional to a partially resilient WEF system. While water constraints are fully resolved, temporal variability in renewable energy supply limits both energy continuity and food production capacity.



Discussion and conclusions

This study introduces a hierarchical, resilience-oriented framework for assessing the Water–Energy–Food Nexus and demonstrates its application through a rural Mediterranean case study. By explicitly embedding energy and water constraints into food production and adopting a non-compensatory aggregation logic, the framework reveals structural vulnerabilities that remain hidden in conventional nexus assessments.

The results show that baseline conditions, despite apparent resource sufficiency, correspond to a functionally non-resilient system due to deep energy dependence. In contrast, relatively modest infrastructural reconfigurations—namely surface water utilization, renewable electricity generation, and short-term energy storage—enable a transition toward high resilience without increasing total resource demand.

Three key conclusions emerge:

1. Resilience is structural, not volumetric
Resource abundance alone does not ensure resilience; infrastructural configuration and energy coupling are decisive.
2. Energy is the primary enabler of WEF resilience
Without reliable and locally available energy, water and food self-sufficiency remain fragile and conditional.
3. Non-compensatory indicators provide clearer policy signals
Hierarchical aggregation prevents the masking of vulnerabilities and offers a conservative yet realistic basis for resilience planning.

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