Deductive Entropy and Sustainability: A Framework for Organisational Persistence in Complex Systems

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Abstract

Sustainability is commonly framed through resource preservation, emissions reduction, ecological protection, social continuity, and economic resilience. These approaches remain essential, yet they do not fully explain why complex systems sometimes fail despite retaining substantial resources. Electrical grids may possess sufficient generation capacity while losing synchronisation. Ecosystems may retain biomass while losing recovery pathways. Institutions may retain formal structures while losing coherence. Energy systems may retain physical capacity while losing the organisational conditions required for stable operation.

This paper presents sustainability as an application of **Deductive Entropy**, a framework concerned with uncertainty, constraint, and the conditions under which systems preserve coherent organisation. The central claim is that sustainability is not only the preservation of resources, but the preservation of a system's capacity to resolve uncertainty under increasing burden. Let S denote Deductive Entropy and let ϵ denote ordering burden. The deductive resolution rate is defined as:

$$R(\epsilon) = -\frac{dS}{d\epsilon}$$

When $R(\epsilon)>0$, a system resolves uncertainty as ordering burden increases. When $R(\epsilon)=0$, the system maintains its current entropy state. When $R(\epsilon)<0$, unresolved entropy accumulates, indicating organisational degradation.

The paper further introduces constraint persistence, denoted Υ, as the capacity of a system to preserve the relationships required for coherent function. A system remains viable while:

$$\Upsilon(\epsilon)>\Upsilon_c$$

where Υ_c denotes the critical threshold below which the system can no longer preserve its prior organisational identity.

The framework is applied conceptually to ecological systems, electrical grids, socio-economic systems, artificial intelligence infrastructure, curriculum innovation, and fusion energy. These apparently distinct domains share a common sustainability problem: the need to preserve coherent organisation under increasing complexity.

This paper argues that Deductive Entropy offers a unifying mathematical and conceptual language for sustainability science and curriculum design. It allows sustainability to be understood not merely as the conservation of resources, but as the preservation of deductive resolution and constraint persistence under increasing ordering burden.

Keywords

Deductive Entropy, sustainability, complex systems, organisational persistence, curriculum innovation, resilience, constraint persistence, systems thinking, energy systems.