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Sustainability and information in urban system analysis

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Abstract

In the present paper, a possible application of information theory for urban system analysis is shown. The ESM method proposed, based on Shannon's entropy analysis, is useful to evaluate different alternative measures of new energy saving technology transfer at different programming stages for consumption reduction and environmental impact control. A case study has been conducted in an urban area of Florence (Italy): the action/factor interaction entropy values can provide a scale of intervention priority and by comparing results obtained evaluating conditional entropy, ambiguity and redundancy, it is possible to identify the highest energy sustainable intervention in terms of higher or lower critical and risky action/factor combinations for the project being carried out. The ESM method proposed, if applied to different urban areas, can provide a rational criterion to compare complex innovative and sustainable technologies for irreversibility reduction and energy efficiency increase.

Keywords: Sustainability; Thermodynamics; Entropy

1. Introduction

Urban-social organization, built up urban areas and cities can be considered a complex, open system exchanging energy and matter and can be analysed by the two laws of thermodynamics. The basic components of urban systems are people, land, buildings, physical and natural infrastructure, facilities, technical devices and plants which interact with the external ambient made up of other complex systems. Every kind of process requires energy and degrades it in order to transform materials into more useful states for urban system structure and function support. The relationships between material transformation, energy use, waste generation and pollution can be investigated by a thermodynamic approach using the concept of entropy. Thermodynamic analysis requires careful definition of system boundaries in space and time, and knowledge of the form and nature of the processes in the system studied.

Several research projects have used the second law of thermodynamics for urban system analysis

- to apply entropy to urban land use analysis in terms of cybernetics (Phipps, 1981);
- to define dynamic modeling of urban spatial and temporal structure (e.g. for residential location, transport subsystem and economy-production activities) by evaluating energy exchanges between different parts of the system and related entropy fluxes (Ayeni, 1976; Barras et al., 1971; Bjorke, 1996; Ulanowicz, 2001; Wilson, 1983);
- to evaluate sustainability of ecological systems: entropy excess can be reduced by land management that implies information changes in the agro-ecosystem and its surroundings (Ruth, 1995; Steinborn and Svirezhev, 2000).

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Nomenclature

A	area (m^2)
Am	ambiguity (Eq. (10))
Eq	equivocation (Eq. (9))
ety	parameter defined (Eqs.(1)–(2))
H	Shannon entropy (information or neg-entropy)
K	coefficient of the Shannon entropy (Eq. (5))
MA	mesh area (m^2)
n	number (all actions)
P	probability
p	porosity factor
R	redundancy (Eq. (12))
S	entropy (J/K)
T	total information transmitted (Eq. (11))
V	weight or score
W	volume (m^3)
z	number (refereed to all factors/actors)

Subscript

0	maximum
b	building
cv	control volume
empty	referring to empty space of the mesh
F	referring to burning temperature
glass	total transparent surface
i	factor/actor
j	action
s	Sun
$\sum$	sum
tot-disp	total dispersing surface

Other studies have used the Shannon entropy approach:

- to study the nature and structure of interaction patterns and people movements or flows of journey to work subsystems (Chapman, 1970);
- to study random and clustered aspects of settlement patterns for urban and regional model development (Barbera and Butera, 1989).

The applications of Shannon mathematical communication theory in different fields (Gray, 1990; Rogers, 1983; Ruth, 1995; Steinborg and Svirezhev, 2000; Ulanowicz, 2001; Wilson, 1983) show the possibility of defining and quantifying the connection between information and thermodynamic entropy. The basic problem of these applications is result comparison, reading and interpretation. In the present paper, we use the approach suggested by Butera (Barbera and Butera, 1989; Butera, 1999; Butera, 1989) to define and provide a method useful for evaluation of feasibility of different projects applied to a built up urban area. We defined sustainability (Balocco and Grazzini, 2000) as low environmental impact energy durability. The considered projects are finalized to rational utilization of energy resources and their energy sustainability has been measured by lower entropy production.

Thermodynamic entropy assessment of a system, that is connected to its irreversibility processes, can be explained as a measure of neg-entropy or information of the system. The link between entropy and neg-entropy flows, is strictly connected to the concept of resource. Using the Brillouin approach (Brillouin, 1962, Brillouin, 1964) and its developments in the area of living and ecological systems (Ruth, 1995; Wilson, 1983) for information theory application for a thermodynamic system, the resources are neg-entropy flows.

2. Open systems and entropy

The second law of thermodynamics states that the universe or any isolated system spontaneously underpins states with the highest entropy. Whereas non-isolated or open systems can evolve to states with lower entropy than the system itself. When considering a thermal cyclic engine, which is a closed system returning to the initial state for each cycle, all irreversibilities are discharged into the environment as entropy increase. The entropy differences between source and sink permits the production of work. For non-isolated or open systems, sources at low entropy level can be used to decrease the systems' entropy, discharging irreversibilities into the environment. These are wastes. The flux of entropy throughout the system from lower to higher levels can be read as neg-entropy flow from high to low. In terms of statistical mechanics the reduction of internal state to lower entropy values can be considered as an information increase of the system (Zemansky, 1968). Then the entropy can be used to quantify the impact of some project solutions realized on buildings and plants of an urban area. The sustainability is tied to low level of irreversibilities, the evaluation of different solutions for low environmental impact implies higher energy durability (Balocco and Grazzini, 2000). Since solar energy is the neg-entropy source that feeds Earth system, real sustainability can only be obtained if entropy production is lower than neg-entropy flux coming from the Sun (Kreider, 1983).