INTRODUCING THE RESEARCH

ENTROPY DEBT: A LINK TO SUSTAINABILITY?

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ABSTRACT

The thermodynamic laws governing open systems necessitate a cost to system complexity. The cost of system complexity represents an energetic debt in the system's surroundings called 'entropy debt'. This research begins with the premise that municipalities can be understood as complex, open systems and as dissipative structures. They garner energy (i.e. 'energy throughput') from their surroundings to build internal 'system complexity' such as social order, infrastructure, and communication networks. Regarding natural resources, the entropy debt of community complexity is the impact communities have on their natural environment – defined in this research as 'community entropy debt'. Environmental impact is problematic when it compromises the ecological integrity of the natural resources upon which communities rely. Given the necessary relationship between energy throughputs, in the form of natural resources such as food, fiber, and fuel, and community complexity, maintaining ecological integrity is paramount to community sustainability. Yet, despite community dependence on the natural environment, air, water, and terrestrial pollution and loss of sensitive ecosystems continue.

This research asks, how can an open systems conceptual framework highlight the energetic-entropic relationship between the system complexity of municipalities and the natural environment? How can such a conceptual framework effectively be operationalized and applied to municipalities? Finally, what can an analysis of the conceptual framework parameters reveal about systemic drivers of anthropogenic environmental degradation?

First, this research views five British Columbia municipalities through the conceptual lens of the theory of dissipative structures. Second, this research abstracts from the conceptual framework an analogical model comprised of these inextricably linked parameters: 'energy throughput', 'system complexity', and 'entropy debt', to which the corresponding dimensions of municipalities and the natural environment are mapped. Third, this research identifies and applies surrogate measures for each parameter and then compares the data for each municipality. This paper introduces the research and highlights some of the preliminary data.

Key words: entropy debt, open systems, theory of dissipative structures, energy throughput, complexity, sustainability, environmental degradation, conceptual framework

INTRODUCTION

The findings of the Millennium Ecosystem Assessment (MEA) suggest that the current rate of anthropogenic environmental degradation is compromising our future generations from meeting their ecological service needs. "The changes that have been made to ecosystems have contributed to substantial net gains in human well-being and economic development, but these gains have been achieved at growing costs in the form of the degradation of many ecosystem services … " (MEA, 2005, p. 1). In fact, the MEA (2005) states that, due to human activity, approximately 60 percent of the world's ecological services have been degraded or are being used unsustainably (p. 1). Notably, these MEA findings of global ecological resource degradation persist decades after Rachel Carson's (1963) book *Silent Spring* awakened the public's environmental consciousness in the West.

The reasons given for our continued unsustainable use of ecological services vary. For example, research compiled by the World Resources Institute posits that issues of empowerment and social justice lie at the heart of environmental degradation (MEA, 2005). Other research posits that human system complexity needed to meet external conditions, such as the demands of the natural environment or the global economy, lies at the heart of environmental degradation (Adams, 1988; Allen et *al.*, 2003; Bar-Yam 1997). The study of societal complexity in the context of sustainability is among the research that proposes open system conceptual frameworks to study human and natural environment systems.

Open systems conceptual frameworks, specifically those nested in ecological and thermodynamic concepts, provide researchers with opportunities to reveal systemic patterns and relationships (Rapoport, 1985) of human and natural environment systems. Thus, they have made significant contributions to the literature that Kates et *al.* (2001) call the 'emerging sustainability science'. Grounded in this literature, the research introduced in this paper starts from the premise that communities behave according to the principles of open systems, more specifically, to the theory of dissipative structures (Allen, 1997; Dyke, 1988; von Bertalanffy, 1968; Prigogine & Stengers, 1984) and includes the concept of 'entropy debt' (Dyke, 1988; Straussfogel and Becker, 1996). Briefly, as dissipative structures, open systems garner energy from their surroundings to build internal complexity. However, system complexity comes at an entropic cost to the system's environment, referred to as its 'entropy debt' (Dyke, 1988; Straussfogel and Becker, 1996). Based on the theory of dissipative structures, this research operationalizes an open systems conceptual framework for the purpose of highlighting the energetic-entropic relationship between community complexity and the natural environment. Such a framework offers opportunities to elucidate some systemic drivers of environmental degradation.

CONTEXT: APPROACHES TO SUSTAINABILITY RESEARCH

Open systems conceptual frameworks are pervasive in research of ecosystems and social systems. In 1979, Lovelock boldly argues that the Earth is a living system. Twenty years later and within the larger context of complexity science, Levin (1998) describes the biosphere as a complex adaptive system. In the social sciences, some systems research dates to the early years of general systems theory with Talcott Parson's *The Social System* (1951). Emerging in anthropological studies of the energy requirements of societies (Rapapport, 1971; Kemp, 1971), open systems frameworks have expanded to include research of growing and collapsing civilizations (Tainter, 1988) and societal processes (Adams, 1982; 1988). Moreover, a rich array of conceptual frameworks has been developed in recent years to better understand the relationship between humans and the natural environment. They include, system resilience (e.g. Holling, 2001; Adger, 2000), socio-economic metabolism (e.g. Ayers & Simonis, 1994), exergy analysis (e.g. Bejan, 2002; Wall, 1977), emergy analysis (Odum, 1996), entropy law in economics (e.g. Georgescu-Roegen, 1971), and dissipative structures frameworks.

Resilience frameworks

Resilience theory is among the influences stemming from and continuing to further the theory and management of ecosystems (Jørgensen & Müller, 2000). Ecologist, C.S. Holling (1973) distinguished the concept of system 'stability' from its 'resilience', maintaining that the measure of ecosystem health is not its ability to return to initial conditions when faced with some external shock, but the ability to absorb the shock without losing its systemic integrity. A conceptual framework fundamental to resilience theory is the adaptive cycle, whereby, "social-ecological systems … are interlinked in never-ending adaptive cycles of growth, accumulation, restructuring, and renewal" (Holling, 2001, p. 392). The conceptual framework of the adaptive cycle has been studied in many contexts including the responses of ecosystems to resource management institutions and personal or corporate crises (p. 394). Adaptive cycles have also been explored in terms of system hierarchy, called 'panarchy', whereby adaptive cycles interact across scales (Gunderson and Holling, 2001). Resilience research maintains that sustainability "is the capacity to create, test, and maintain adaptive capability" (Holling, 2001).

Exergy frameworks

Exergy has become a powerful conceptual and analytical tool in the study of engineered systems (e.g. Bejan, 2002; Lozano & Valero, 1993) and self-organized systems (e.g. Kay, 2000; Wall & Gong, 2001, Gong & Wall, 2001). Exergy is energy used in the process of performing work. As in ecological systems, natural resources provide a gradient of energy (Wall, 1977) to be consumed in the performance of work by systems with an internal structure or organization capable of doing so (Jørgenson, 2000), including societal systems. Wall (1977) defines natural resources as deposits (e.g. oils, minerals), funds (e.g. plants, animals), and natural flows (e.g. running water, sunlight, ocean currents). This exergetic framework (Wall, 1977) conceives known and profitable natural resources as reserves, the use of deposits as unsustainable, and the use of funds and natural flows as potentially sustainable (Wall & Gong, 2001). Sustainability, examined exergetically, is defined by Wall and Gong (2001) as the stable balance of the use of funds and deposits with their generation via solar inputs.

Emergy theory & analysis

'Emergy', the term dating back to 1983 (Odum & Odum, 2001), has emerged from the theory that self-organizing systems survive in the natural environment by maximizing energy consumption most efficiently, i.e. by 'empower' (rooted in biologist Alfred Lotka's maximum power principle (1922)). More specifically, H.T Odum's (1996) maximum empower principle is central to the conceptual framework that holds that, "In the self-organizational process, systems develop those parts, processes, and relationships that maximize useful empower" (Odum & Odum, 2001, p. 71). Emergy refers to the, "available energy of one kind that has to be used up directly and indirectly to make a product or service" (Odum & Odum, 2001, p. 67). As such, natural capital, itself the product of the flow of solar energy, embodies emergy. Brown and Ulgiati (1999) define natural capital as the stores (i.e. nonrenewable and renewable) "of material and energy from which environmental services are drawn" (p. 3). Therefore, emergy further links societies and their economies to the flows of solar energy embodied in natural capital, which humans utilize to generate products and services (p. 3).

The entropy law & ecology in economics

The field of economics incorporates ecological and thermodynamic concepts. Exemplifying thermodynamic concepts in economics, Georgescu-Roegen (1971) published, *The Entropy Law and the Economic Process*. The premise of this publication is that thermodynamic laws, specifically, entropy, governs economic processes. Mulder and Van den Bergh (2001) explain that the Second Law also provides a useful construct to understand environmental degradation with respect to the economic process. In this sense, dissipation of energy (i.e. entropy production) impacts the natural environment in the anthropocentrically defined and 'negative' context of environmental degradation encompassed in the discussion of (un)sustainability. An early contribution to biophysical thinking in economics came with Boulding (1966), who spoke of Earth, its finite resources, and its economies as a spaceship – and the economy as a "spaceman economy". The conceptual frameworks of socio-economic metabolism provide more recent examples of biophysical concepts in economics. For example, a study conducted for the World Resources Institute (Matthews et *al.*, 2000) tracks the annual tonnes of material resources required and produced by a selection of nations with developed economies.

Dissipative structure frameworks

The theory of dissipative structures presented by Prigogine and his colleagues (Prigogine et *al.*, 1977; Prigogine & Stengers, 1984; Nicolis & Prigogine, 1989) has emerged in conceptual frameworks applied in the social and natural sciences. In the natural sciences, the theory of dissipative structures has been applied to the study of living systems. For example, Kay (2000) states, "Life should be viewed as the sophisticated end in the continuum of development of natural dissipative structures from physical, to chemical autocatalytic, to living systems" (p. 10). In the social sciences, the theory of dissipative structures has been applied to the rate and patterns of growth of cities (Allen, 1997; Dyke, 1988; Straussfogel, 1991). Similarly, Adams (1982; 1988) sets out a detailed conceptualization of society and its evolutionary processes as conduits of energy – specifically, as dissipative structures. More specific to the study of sustainability, Straussfogel and Becker (1996) propose the theory of dissipative structures as the theoretical basis for assessing and mitigating human impact on the natural environment. Ho and Ulanowicz (2005) derive sustainability indicators by analyzing large scale human systems (i.e. agriculture, economics) by way of the characteristics of organisms (as dissipative structures). These characteristics, the authors argue, represent, "an ideal sustainable system" (p. 39). Alberti (1996) views cities as dissipative structures and then develops a conceptual framework of interrelationships based on dimensions of sustainability (i.e. social and ecological). These are used to assess the qualities of 'urban ecological space'. On a smaller scale yet, Hermanowicz (2004) examines entropy change and energy flux in simple systems called unit operation and processes (UOP). His paper seeks to clarify the definition of sustainability by applying thermodynamic fundamentals to relatively simple dissipative systems.

OPPORTUNITY: OPERATIONAL ENTROPY DEBT

As discussed, open systems conceptual frameworks – whether conceptually ecological or thermodynamic - have contributed insights to sustainability science, by offering definition and measure of, or management practices toward, sustainability. Each conceptual framework offers an opportunity to highlight an important aspect of human-environment systems. The opportunity is held in the unique conceptual principles embodied in the framework. Thus, operational conceptual frameworks, that is, those applicable to a given system, highlight aspects of the system under investigation for further analysis.

Conceptual similarities

The research highlighted in this literature review share several aspects in common. First, they share in common a systems approach to studying the relationships between humans and the natural environment. Second, they utilize open systems conceptual frameworks in order to do so. Finally, they explore some or all of the following research steps. They 1) explore theoretical principles, in this case, ecological and/or thermodynamic, 2) develop a general conceptual framework based upon these principles 3) operationalize the conceptual framework to a specific system to elucidate, "phenomena, to order material, revealing patterns" (Rapoport, 1985). This step requires 'mapping' the theoretical principles to the system under investigation. In some cases, researchers 4) further develop analytical tools, such as indices and measures, having repeatedly operationalized the framework with inductive research.

Conceptual differences

Yet, fundamental differences between each type (i.e. ecological or thermodynamic) provide unique conceptual and, therefore, operational advantages. For example, the ecological approach conceives human systems as nested hierarchies of interdependent systems, which exist within ecological systems. The human societal and ecological system is, in effect, coupled (Lui et *al.*, 2007), thereby eliminating the need to explicate the boundaries 'between' human and ecological systems for some analysis. This conceptual approach effectively highlights the capacity of the entire system to adapt to change over time, for example, due to ecological disturbances caused by humans. As such, the ecological framework lends itself, operationally, to analysis of practices toward sustainability. As an example, Berkes and Folke (1998), focus on the link between human (i.e. social) and ecological systems by examining case studies of adaptive natural resources management practices. Similarly, the research conducted by Gunderson et *al.* (1995) is premised on the idea that, "Finally, sustainable development is neither an ecological problem, a social problem, nor an economic problem. It is an integrated combination of all three. Effective investments in sustainable development therefore simultaneously retain and encourage the adaptive capabilities of people, business enterprises, and nature" (p. 32).

Alternatively, the thermodynamic approach offers sustainability research a rich conceptualization of the energy, matter, and information resources derived from the natural environment required to sustain human systems in various states of complexity. In addition, it lends itself to analyzing environmental impacts from human activity. This opportunity is possible because of its conceptual capacity to differentiate the system from the system's external environment. This is evidenced in the conception of the entropy law in economics, elucidating the 'ecological debt' (Rees & Wackernagel, 1996) that economic systems incur in nature.

Moreover, conceptual frameworks based on dissipative structures engender further opportunity to highlight the relationship between energy throughput, entropy production or ‘entropy debt’, and system complexity of any system deemed to be a dissipative structure. This opportunity is particularly advantageous in the study of human systems as dissipative structures, in their relation to the natural environment upon which they rely on natural resources.

Yet, while the literature exploring the theory of dissipative structures has contributed to our understanding of human and natural environmental systems as dissipative structures, its contributions to sustainability science could be more robust. For example, Alberti (1996) views cities as dissipative structures. Yet, the author develops a framework based on dimensions of sustainability (i.e. social and ecological) to assess the qualities of ‘urban ecological space’, rather than dimensions of dissipative structures. In another example, Adams (1988) views society as a dissipative structure. However, although Abel (1998) admits that while Adams (1988), “produced a groundbreaking and extensive synthesis of much of complexity theory with anthropology … by incorporat[ing] many of the issues raised by complexity theory …”, this work does not extend analysis to human impact on the natural environment.

A link to sustainability?

The proposed research is further guided by the discussion that societal system complexity is driven by the constraints and opportunities imposed on the system by the system’s environment (Adams, 1988; Bar-Yam, 1997; Allen et *al.*, 2003). These external constraints might include demands imposed by the natural environment or the global economy, or the forces of technological innovation. Yet, neither all societies, nor communities within those societies, appear to negatively impact ecosystem services equally or for the same reasons. For example, Holling (2001) argues that human systems are unique in that they are forward-thinking and intentional. And Adams (1988) admits that some societies “use a great deal more energy than others” (p. 24). Clearly, it is possible for the ‘internality’ (Macy, 1991) of societal system complexity to differ given the same external constraints. Allen (1994) provides this argument,

> So much of human attention is focused on playing a role in groups where values are generated internally, and the physical world outside is largely irrelevant. It is therefore naïve to believe that underneath the rich tapestry of life there is a rational scheme within which the complexities of the world would appear as being necessary and unavoidable … Evolution is creative beyond reason, and in that lies its resilience, since it is not framed to respond to any particular limited scheme (p. 94).

As such, it should be just as possible for human system complexity to impact the degree of environmental degradation as the assertion that external conditions drive human system complexity.

This paper argues that an important research endeavor is one that develops an open systems conceptual framework capable of highlighting the energetic-entropic relationship between human systems and the natural environment upon which they rely. This research proposes that, operationally, such an open systems conceptual framework can explore the idea that human systems can be different from one another given the same external constraints. It further explores the possibility that doing so could reveal systemic drivers of environmental degradation.

OVERVIEW OF THE RESEARCH

The research asks 1) how can an open systems conceptual framework highlight the energetic-entropic relationship between community complexity and the natural environment? 2) How can such a conceptual framework effectively be operationalized and applied to community systems? Finally, 3) what can an analysis of the conceptual framework parameters reveal about systemic drivers of anthropogenic environmental degradation?

The objectives of the research are to:

1. Identify an open systems conceptual framework that highlights the energetic-entropic relationship between human system complexity and the natural environment
2. Map the conceptual framework to selected human systems
3. Operationalize the conceptual framework by establishing surrogate measures for the parameters: energy throughput, complexity, and entropy debt
4. Evaluate the links between the surrogate data of community complexity, energy throughput, and community entropy debt

Some preliminaries

The following sections describe some of the considerations undertaken early in the research to define each term. This was necessary before surrogate data could be selected and an analysis could be conducted.

Rationale to select the municipalities
To isolate the internal structural differences that impact anthropogenic environmental degradation, this research selects municipalities that are constrained by similar external conditions. This is based on the theory that external conditions constrain the internal complexity of dissipative structures (Prigogine and Stengers, 1984). Therefore the selected municipalities were subject to similar climatic, economic, and political influences. They were also selected for political and social stability and similar population sizes. Five municipalities in British Columbia, Canada, met these selection criteria. Located geographically on Vancouver Island, politically in the same Regional District in close proximity to the provincial capital, Victoria, and subject to the same climatic conditions, the following municipalities contain similar population sizes: Central Saanich (pop. 16,347), Colwood (pop. 14,768), Esquimalt (pop. 17.229), Langford (pop. 21,585), and Oak Bay (pop. 18,853) (BC Stats, 2004).

Rationale for surrogate data of 'energy throughput'
The theoretical definition for the energy throughput of a dissipative structure is the matter, energy, and information resources garnered by the open system and used to maintain its internal complexity via the dissipation of that throughput (Prigogine & Stengers, 1984). In the context of human societies and their subsystems, Adams (1988) explains,

> While most people would have no problem in conceiving of coal or petroleum as energy forms, the present argument requires that we also regard human beings, human behavior, social groups, and assemblages of social interactions as energy forms. Similarly, mental processes located in the brain, writing on paper, and sound waves in the air are also energy forms (p. 16).

While it is impractical to quantify all energy sources that support the self-reproduction of community systems, consumer energy sources of fiber, fossil fuel, and hydro-electricity provide a surrogate measure for the energy requirements of community systems in industrialized countries. Wall and Gong (2001) state that, "Industrial society only uses a very small part of the direct exergy flow from the sun, e.g. within agriculture and forestry" (p. 140). In fact, they estimate that the majority of the exergy used within industrialized society originates from fossils fuels (62%), the rest of which, "is composed of mainly wood for construction and paper, firewood, food, hydro power and nuclear deposits" (p. 14). On the basis that the majority of exergy of industrialized societies is derived from fossil fuel, fiber, and hydro electricity (Wall & Gong, 2001), the proposed research uses energy consumption data as the surrogate measure of the energy throughput requirement of a community system.

Complexity

Some researchers maintain that self-stabilization, hierarchy (Simon, 1973), and especially, self-organization (Kay, 2000) define system complexity, which is a function of its interacting components or 'parts' (Allen, 1997; Nicolis & Prigogine, 1989). Based on Shannon and Weaver's (1963) theory relating information to entropy, system complexity can also be measured by the information required to describe a system and characterized by the amount of energy used by (Brooks and Wiley, 1986; Adams, 1988) and stored in the system (Kay, 2000) and the complexity profile of behaviors at various scales (Bar-Yam, 1997). For example, the description of a completely random behavior of gas molecules requires more information than the coherent behavior of a corporation. Yet most readers would view the coherent behavior of a corporation as being more complex than the random behavior of molecules. Regarding this, Nicolis and Prigogine (1989) explain, "It is more natural, or at least less ambiguous, to speak of complex *behavior* rather than complex systems. The study of such behavior will reveal certain common characteristics among different classes of systems …" (p. 8). Therefore, this paper defines complexity according to behavioral characteristics, focusing on self-organization, self-stabilization (Nicolis & Prigogine, 1989), and hierarchy (Simon, 1973). Without these fundamental characteristics, complex open systems could not self-reproduce in semi-autonomous relations with other systems (Simon, 1973), but differentiated thermodynamically from their environment (i.e. other systems at various scales), and exhibiting emergent properties based upon subsystem behaviors at all scales (von Bertalanffy, 1968).

Moreover, system complexity defined according to behavioral characteristics as opposed to measures, extends operationally advantageously to any number of data sources describing the emergent properties of a given system. For the selected community systems, descriptive statistics provide one possible source for community system complexity. More specifically, BC Stats and Canada Census data provide municipal-specific economic, social, and demographic information, including population density, dwelling types, and income distributions. While not exact measures of complexity, or representative of indicators of complexity, as surrogate measures, these descriptive statistics offer this research with consistently gathered data with which to evaluate links between the framework parameters.

Entropy Debt

Regarding the theory of dissipative structures, Prigogine and Stengers (1984) explain that the 'structure' or internal organization of an open system (i.e. a dissipative structure) requires energy with which to conduct the work required to maintain or increase that structure. Thus, entropy production of a dissipative structure is the sum of the influx of energy and the irreversible processes internal to the system (Prigogine & Stengers, 1984). Dyke (1988) calls the dissipation of energy necessitated by system complexity 'entropy debt', thereby stressing the cost to the external environment (i.e. disorder) of the system's internal structure (i.e. order). In mapping the concept of entropy debt to municipalities, the entropy debt of community complexity is defined as the sum of: waste outputs from irreversible internal processes and the dissipation of natural resources.

Natural resources, meaning fuel, fiber and food, a component of the total ecological services the MEA (2005) deems necessary for human well-being, represent some of the energy resources external to and upon which human society relies. While their dissipation to maintain or build human systems, including the waste generated via irreversible processes, indeed generates entropy in the greater universe, natural resources are constantly being renewed by the abiotic and biotic processes driven by solar energy. Moreover, some system wastes are absorbed as fuel for others. Therefore, for the purpose of the proposed research, the concept of entropy debt is further defined as 'community entropy debt' to focus on the cost to the natural environment, which in practical terms, is deemed to compromise or degrade the natural resources of the geobiosphere upon which community complexity relies.

While researchers admit that the issue of sustainability is fundamentally anthropocentric, meaning, that it is oriented most fundamentally to the well-being and preservation of human beings (Haberl et *al.*, 2003), the sustainability literature nonetheless defines and provides indicators for the unsustainable use (i.e. dissipation) of natural resources. This research is guided by Azar et *al.*'s (1996) sustainability indicators, which are based on Holmberg et *al.*'s (1996) four principles of sustainability. Briefly, Holmberg et *al.*'s (1996) four principles of sustainability are that 1) lithospheric substances and 2) human-produced substances should not accumulate in the ecosphere, 3) the productivity of the ecosphere should not be degraded, and 4) resources should be used effectively (e.g. not wasted) (p. 17).

Therefore, as surrogate measures of 'community entropy debt', the research will compile municipal-specific environmental data that demonstrate environmental degradation. Ideally, this data will be among those substances deemed to be used unsustainably all the global level (Azar et *al.*, 1996). It will be assumed that those substances being used unsustainably at the global level approximate those at the community level, in Canada - itself an industrialized country. The preferred data will include point, area, and mobile sources of pollutants flowing into the air, onto the land, and into the water. In addition, loss of sensitive ecosystems data, compiled in the Capital Regional District over a ten-year period from 1992 to 2002 (AXYS Consulting, 2005) will serve as an estimate of loss of ecosystem productivity (Azar et *al.*, 1996).

Tabled below is a summary of the framework parameters mapped to the corresponding dimension of the community system and the suggested surrogate measures.

Table 1. A summary of the methodology used to operationalize 'entropy debt'

Framework parameter	*Corresponding dimension of the community system*	*Proposed surrogate measures*
Energy throughput (matter, information, energy)	Energy throughput (matter, information, energy)	Fossil fuel, wood fiber, hydroelectric energy consumption
Internal complexity	Community complexity	Descriptive social, economic, and infrastructural statistics
Entropy debt	Anthropogenic environmental degradation	Environmental statistics of air, water, land emissions from point, area, and mobile sources; loss of sensitive ecosystems; using societal activity data

Surrogate data: Samples and considerations

Municipal-specific data sources are often limited. This is especially so for energy consumption and environmental data. By contrast, census data, which are collated per political area (e.g. municipality or regional district), such as those offered by regional or national governments, are more accessible. Thus both accuracy (i.e. the data are municipal-specific) and adequacy (i.e. the data are robust) pose a potential challenge to the research.

Yet, despite the limitations, a breadth and depth of municipal-specific data exists for the five selected community systems. Energy consumption data were retrieved from an energy consumption and air emissions study (McEwen & Hrebenyk, 2006) conducted by an environmental consulting firm on behalf of the Capital Regional District (i.e. the regional government), of which the five selected municipalities are a part. These data are municipal-specific and measure consumption and emission for the year 1995 and 2004; moreover, they are based on societal activities. The study is a compilation of data from a variety of sources, ranging from household energy consumption rates directly from energy providers to estimates of air emissions based on emission factors. A sample of this data is found in Table 2 and 3.

Table 2. Sample of preliminary municipal energy consumption data - 1995

Community System Energy Consumption - Buildings & Transportation: 1995					
Energy type and use (GJ)	Community systems (i.e. municipalities)				
Building Energy Consumption (GJ)	Central Saanich	Colwood	Esquimalt	Langford	Oak Bay
Natural gas - residential	21,011	18,477	15,424	20,038	46,160
Natural gas - commercial	96,780	41,635	133,277	119,721	89,406
Natural gas - industrial	46,895	47,075	212,455	16,396	25,731
Light fuel oil - residential	217,697	185,874	160,228	271,135	229,620
Electricity - residential	342,109	255,473	243,065	330,972	334,399
Electricity - commercial	123,630	94,350	124,637	106,574	101,980
Electricity – industrial	30,071	6,870	192,990	29,912	1,087
Transportation Energy Consumption (GJ)					
Gasoline & diesel	417,273	279,808	300,137	477,115	278,234
Total Building & Transportation Energy	*1,336,425*	*965,007*	*1,423,949*	*1,422,879*	*1,152,616*
From "Greenhouse gas and energy use inventory for the Capital Region 2004," by B. McEwen & D. Hrebenyk, 2006, Prepared for the Capital Regional District by SENES Consulting Ltd.					

Table 2 lists preliminary annual consumption rates of energy (GJ) per municipality as community system in 1995. Consumption rates are further delineated per use (i.e. building, transportation) and user type (residential, commercial, industrial). For example, these data were compiled from a number of different sources as per the original study (McEwen & Hrebenyk, 2006). For example, the hydro-electricity consumption rates were retrieved directly from the energy provider (of which there was only one for this energy type) for 1995 and 2004. The natural gas data were also retrieved from the energy provider; however, 1995 consumption rates were estimated for the Regional District using gross population differences and then allocated per municipality using the same percentage of users as in 2004. Data that were normalized per capita were omitted from the final tables.

Table 3. Sample of somepreliminary air emissions data for Central Saanich - 2004

Central Saanich - Air Emissions: 2004								
Source	Type	Air Emissions (tonnes)				GHGs (tonnes)		
		NO_x	SO_x	NH_3	VOC	CO_2	CH_4	N_2O
Point	*Industrial*	0.7	0.1	0.0	0.3	0.0	0.0	0.0
Area	*Agricultural Sources*	1.3	0.2	85.5	51.8	0.0	103.1	24.7
	Space heating							
	Natural Gas-residential	3.5	0.1	0.0	0.2	4482.3	0.1	0.1
	Light fuel oil – residential	9.0	0.2	0.4	0.4	11740.1	0.9	0.0
	Natural Gas-commercial/industrial	6.6	0.1	0.0	0.4	7951.2	0.2	0.1
	Commercial activities							
	Bakeries	0.0	0.0	0.0	0.3	0.0	0.0	0.0
	Dry cleaning	0.0	0.0	0.0	0.5	0.0	0.0	0.0
	Metal degreasing	0.0	0.0	0.0	15.4	0.0	0.0	0.0
	Surface coatings	0.0	0.0	0.0	55.7	0.0	0.0	0.0
	Printing inks	0.0	0.0	0.0	5.2	0.0	0.0	0.0
Adapted from "Capital Regional District Air Contaminant Emissions Inventory for 2004," by B. McEwen and D. Hrebenyk, 2006, Prepared for the Capital Regional District by SENES Consulting Ltd. (Available from the Capital Regional District, 625 Fisgard St., Victoria BC, V9W 2S5).								

Similarly, Table 3 lists preliminary air emissions of criteria air contaminants for point, area, and mobile (not shown here) sources. For example, as per the original study (McEwen & Hrebenyk, 2006), point source data were compiled using data provided by provincial and federal government permitting agencies. Area source data were estimated using emission factors. Mobile source air emissions data were estimated using a traffic modeling study. The mobile source data were allocated to each municipality based on the number of estimated kilometers traveled per household per municipality. However, some emissions were allocated to each municipality in the Regional District per capita. Again, these data were not included in the final tables. Another surrogate measure of the 'community entropy debt' framework parameter includes data of the loss of sensitive ecosystems. A study conducted between 1992 and 2002 (AXYS, 2005), which digitized losses of sensitive ecosystems, provided data in units of hectares per municipality.

Although not provided here, surrogate measures of community complexity included Canada Census data for 1996 and, ideally, 2006. These included demographic, population density, housing type, median distance from work, and economic structures data per municipal population.

Next Steps

The final objective of this research was to identify the links between the surrogate measures of energy throughput, community complexity, and community entropy debt. Yet, no specific method in the literature can serve as a guide on exactly how this should be done. This research conducted a method of analysis derived from the premise that energy throughput and internal complexity are directly related (Adams, 1988; Kay, 2000; Prigogine & Stengers, 1984) and that entropy debt and energy throughput are directly related. Therefore, if surrogates of community entropy debt depend on the amount and type of energy consumed; and, if the amount and type of energy consumed depends on surrogates of complexity (i.e. complexity variables) then the results of the following methods will elucidate the complexity variables that are linked to energy consumption. The results will also elucidate the amount and type of energy consumption that is linked to the surrogates of community entropy debt.

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CONCLUSION

The research that this paper introduces starts from the premise that communities are complex open systems that behave according to the principles of open systems, and more specifically, to the theory of dissipative structures (Adams, 1988; Allen, 1997; Dyke, 1988). As dissipative structures, they garner energy from their surroundings to build internal complexity such as, social order and infrastructure. This is the energy throughput required by the community system to maintain its system complexity. Reciprocally, the entropy debt of community complexity is defined as the cost to the natural environment of maintaining (and building) community complexity and is called 'community entropy debt'. A conceptual framework based on the principles of open systems, more specifically, on the theory of dissipative structures has the capacity to highlight the energetic-entropic relationship between community complexity and the natural environment. Moreover, the challenges and opportunities of operationalizing such a conceptual framework in the context of community systems will offer unique lessons about the methodology this research will undertake. Finally, once operational, an analysis of the framework parameters may offer a unique opportunity to reveal some systemic drivers of environmental degradation.

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