Title
Sustainable Development: Physical and Moral Issues

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Publication Date
2006-12-01

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Sustainable development gradually becomes an important concept embedded in many societal activities including economy, politics and perhaps even regulations. Sustainability is now a growing concern of businesses, governments, civic groups and individuals. These concerns are often linked to energy efficiency, reduction of environmentally harmful emissions, ecosystem preservation and other "save the Earth" efforts. They are becoming a part of a "triple bottom line" for business accounting: financial, social and environmental. Despite its increasing importance, current definitions of "sustainability" are somewhat vacuous. The most commonly accepted description was provided by the World Commission on Environment and Development in 1987 in the so-called "Brundtland Report"[1]. The professed goal of sustainability is to "meet the needs of the present generation without compromising the ability of future generations to meet their own needs." Other descriptions are similarly phrased and often confuse sustainability with environmental protection and other lofty goals that, strictly speaking, are not required for sustainable operations.

Morality and ethics

While a better definition (or definitions) of "sustainability" is highly desirable, the principle espoused in the Brundtland report is quite clear. It calls for modifications of current human activities in recognition of their adverse effects on future generations. The "business as usual" scenario of global development would lead to severe adverse consequences in the future according to its critics. Hence, the repeated calls for profound changes in many areas of human life, often tinged with cataclysmic predictions. However, what is mostly missing in these appeals and the ensuing debates are the moral or ethical aspects of the proposed solutions and modifications. Two fundamental questions should be answered convincingly and with clarity. First, how do we justify the imposition of limitations and perhaps sacrifices by currently living human beings, individuals with dreams and aspirations, to benefit some abstract unborn, future generations? Secondly, if such impositions can be justified, who has the right to impose them and through what process?

These are not trivial questions[2]. On one hand, they affect a Chinese peasant, an American teenager, a German worker, a Nigerian schoolgirl, individual distinct persons, all of whom desire to realize their goals in life and fulfill their destiny. Why should we tell a peasant ploughing the field with oxen that he cannot follow the example of a Canadian farmer and have a diesel tractor? Why should not a bicycle-riding teenager in Shanghai yearn to have his muscle car if he can see on TV the low-riders of his contemporaries in LA? We may consider such ambitions "foolish", "inappropriate", "undesirable" or "unrealistic" but they are nonetheless real ambitions of real people. We compare these desires with the speculative needs of yet unborn collectives from a distant future removed from us by many generations. Our global scenarios often try to predict the development for several decades or even centuries into the future. Why should we care about potential people who have no conceivable direct links with any of us, whose needs we cannot comprehend, and whose wealth and technological sophistication is likely to exceed our imagination? Aren't we similar to early nineteen century shipbuilders who worried about the lack of trees suitable for masts and rigging? As they perceived the future lack of timber, they planted oak trees and contorted their branches to yield suitable shapes of ship hulls. Little they expected that by the time their oaks matured, steamships would ply across the seas rendering their fears obsolete.

Furthermore, if changes to current or potential lifestyles need to be implemented through which process should they be achieved? Is it a responsibility of national governments, multinational or transnational bodies, market forces, civic organizations, groups of experts, benevolent dictators or Platonian philosopher kings? Should we use currently existing political processes with their large variety or do we need to devise another decision-making process in view of global and long-term consequences of the sustainability goals?

I want to stress the necessity of addressing these fundamental questions, especially if we are convinced that the aims and objectives of sustainable development are right and justified. Only a full, convincing and public articulation of the reasons behind these objectives will lead to public acceptance and implementation. If the proponents of sustainable development shirk or abrogate this duty, the sustainable development will remain an unfulfilled idea or a burdensome obligation. Perhaps, the development of the concept of democracy can offer a useful lesson. While the very idea of democracy has deep historical roots, the acceptance of its fundamental tenet of "one person, one vote" is only a recent phenomenon that was achieved through an open and persistent exposition of this principle. The idea of democracy was debated and won, despite sometimes vehement and brutal opposition, because of its clear moral superiority. This victory of the democratic idea is now so universal that even the despotic regimes, where the implementation of democracy is greatly lacking, pay at least lip service to the concept. In a similar way, the idea of sustainability must become universally accepted.

Sustainability and Change

Sustainability is commonly associated with persistence or permanence. A dictionary definition of the word "sustainable" contains the elements of maintenance and stasis but also of support, nourishment and service. The development, on the other hand, seems to contradict sustainability as it implies change, dynamic movement and instability. Thus, we must address this apparent disagreement and elucidate what we want to sustain and what we want to develop. Otherwise, the idea of the sustainable development will not be accepted at large. Even the proponents[3] of sustainable development take a very sober view of its mass appeal, *"Surveys found that few had heard the expression, but, on hearing it, they took sustainable to mean static - requiring that one always drive the same car, have the same amount in the bank, and live in the same house. So the term sustainable development is unlikely to rally millions to the cause of sustainable development."*

Some degree of clarity can be achieved if we enumerate what we want to sustain and what we want to develop. For example, the following list is probably uncontroversial and agreeable to a vast majority of people:

Sustained	**Developed**
Earth	People
Life Support	Economy
Community	Society

However, the tension between the desire to maintain some aspects of our life, natural environment or social fabric, and the wish to change other features of the same set of elements is mostly unavoidable. Fortunately, such tension is a common human experience and can be dealt with psychologically. The change is accepted and even welcome if it is constrained within some limits.

Graphically, we can think about a trajectory of our system in a multidimensional space of state variables, the so-called phase space. Each axis represents the values of one variable that is relevant to system description. It could be energy consumption, material output, fish population or GDP/capita, whatever is appropriate. Thus, a line in the space defined in this way, describes the progression of states the system goes through. Time is implicitly recognized as a movement of a point on the line. An example in Figure 1 (taken from a wonderful book "Turbulent Mirror"[4]) shows a hypothetical relationship between populations of two types of fish in a lake and anglers trying to catch them. The advantage of such representation is a clear and visual representation of sometime complex systems. In this example, it is obvious that the populations of trout and anglers are positively correlated although with some time delays.

In the phase space, the trajectory of a system may be described by an unbounded line corresponding to unrestricted, unmitigated changes. In another case, the trajectory may lead to a single point that represents a static equilibrium such as examples[5] in Figure 2. It seems that both of these cases may not be desirable or even feasible, both for physical and social systems. A closed loop (such as in Figure 1) is yet another possibility of the system trajectory. In this scenario, the system follows a cyclical pattern passing periodically through the same stages. While theoretically possible, the exact periodicity is rarely if ever found in real systems due to variable influences of a myriad of factors nudging the system away from exactly repeating itself.

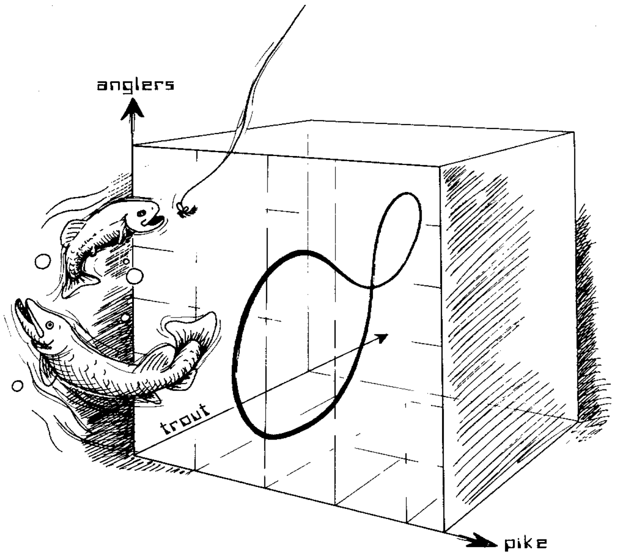
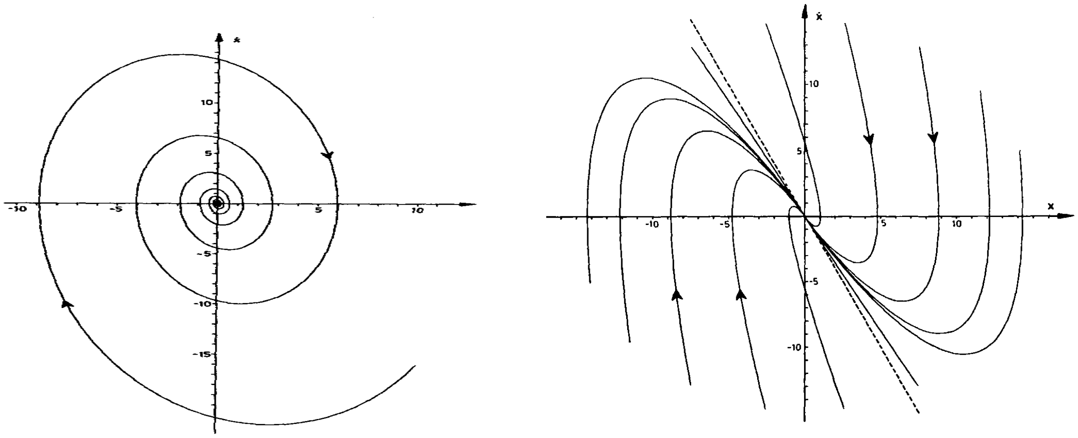


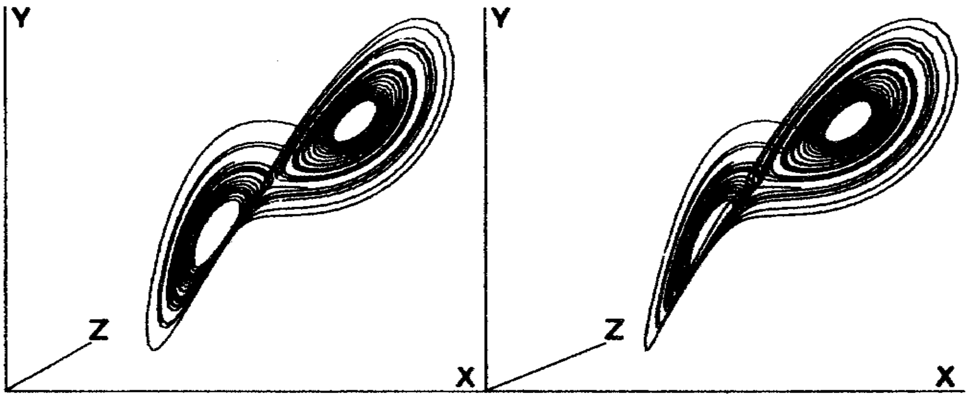
Figure 1. System trajectory in the phase space



Thompson, J.M.T., Stewart, H.B. (1986). Nonlinear dynamics and chaos. Wiley

Figure 2. Examples of trajectories leading to stable equilibrium points; to represent unstable conditions, reverse the time arrows on the lines

Perhaps the most apt description of a sustainably developing system may be that of a "strange attractor". This term, borrowed from the theory of nonlinear dynamics, describes a trajectory of a system that is bound in the phase space, i.e., for which all its variables change but within limits. At the same time, the system development does not follow a strict pattern but is not completely random and haphazard. These systems have been extensively studied in natural science (mostly physics and chemistry) but also conceptually applied to social systems such as a business enterprise[6] or politics. One of the earliest example of "strange attractors" comes from the area of atmospheric modeling and became to be known as the Lorenz attractor after Ed Lorenz who discovered[7] it in 1960s.



Urbach, R.M.A. (2000). Footprints of Chaos in the Markets. FT-Prentice Hall

Figure 3 Lorenz attractor, the earliest example of a strange attractor; to see its three-dimensional structure try to cross your eyes to merge the left and right images in one.

As seen[8] in Figure 3, the system, now characterized by three variables, moves through a bounded region of the phase space but it is neither periodic nor leading to a fixed equilibrium. Instead, for a while the system moves around a point, in a quasi-periodic fashion, and then loops off to another lobe circling around another point. The behavior repeats itself but not exactly; for example the times between switching from one to another lobe do not follow any discernible pattern. However, it is important to note that the system is stable as it does not run away in any direction. At the same time, its behavior is not random as the attractor has a definite structure.

An example of real environmental system dynamics is shown in Figure 4. The diagram shows daily flows in three channels that form a part of the Sacramento-San Joaquin Delta in California, a very complicated hydrologic system that is also a subject of intense political battles about water allocations and control.

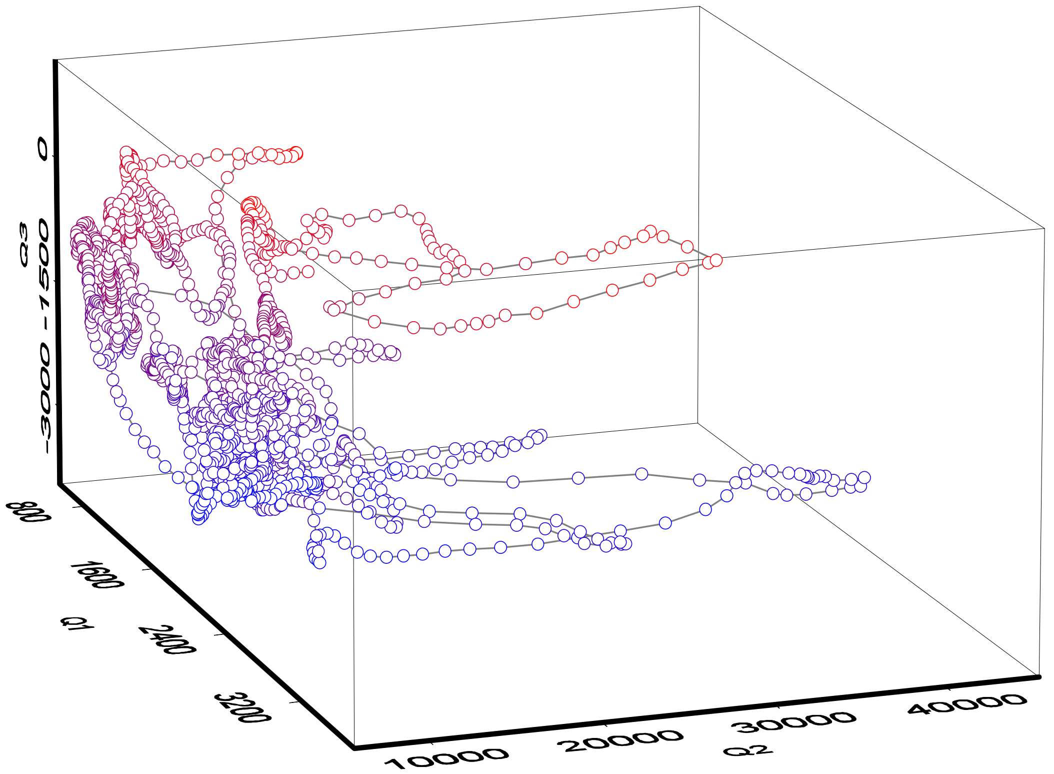


Figure 4 Dynamics of a river system. Each axis represents water flow in a river channel.

As seen in this representation, the hydrology of the system evolves in a complex way over the period of several years. While the phase space representation (indeed a “strange” attractor) may provide insights in the inner workings of the system, from the sustainability perspective it is important to note that this system seems to be quite dynamic with two large flow excursions shown as two protruding loops. At the same time, the system trajectory is contained, returning to the lower left-hand corner even after large transients. At least on the time scale captured by the graph, the system seems to be sustainable.

The paradigm of a dynamic system evolving along a strange attractor may be useful in principle to imagine a sustainable system since it combines the limits with changes. However, it is the degree (and details) of preservation and modification that arouse controversy. What limits should be set on each variable? What rate of change is acceptable or advisable? Should all system states be equally accessible? For example, are the large flow excursions seen in Figure 4 compatible with sustainability? Such questions invariably lead to the necessity of metrics and measurements. The need for metrics is probably the biggest challenge to wider acceptance of sustainable development. Without metrics, no progress can be measured and achieved. Properly designed metrics can greatly facilitate the discussion and help to define the goals while poorly constructed metrics obscure the real problem.

Metrics of sustainable development

As more organizations and individuals grapple with the concept of sustainable development, a variety of measuring tools have been proposed. They range from simple qualitative indicators, often in form of questionnaires, to more quantitative and complicated measurements. One group of these indicators is concerned with **processes** leading toward sustainability. These may include questions whether a particular organization adopted an audit or certification process or how is the issue of sustainability incorporated in the organizational structure, management and reporting. A classic example of such indices could be a fraction of businesses in an industrial sector that adopted the ISO 14000 standards. Another could be the percentage of funds an NGO actually spends on its professed goals *versus* its ancillary activities. While these indicators may point to the overall direction or assess the sincerity of intentions, they do not directly and explicitly describe the state of a system in question, be it an ecosystem or an industrial production facility. That task can be achieved, at least in principle, by quantitative measurements of different characteristics of the studied system.

Each quantitative characteristic can define one dimension of the phase space and be represented along one axis. Some examples of such quantitative measures include greenhouse gases emissions, energy consumption (although since energy does not disappear it is a misnomer), specific pollutant (e.g., PCB, mercury, etc.) loads, fish population, atmospheric ozone concentration and so on. These indicators may be useful tools to characterize environmental protection or ecoefficiency but they do not address individually the issue of sustainability. We may argue that each of such indicators may point in a desirable direction (i.e., lower pollution generation or higher fish population. However, they do not describe the system as a whole. This analytical deficiency becomes more apparent if we consider the dynamics of the system where some or all of the indicators change in time, either due to natural dynamics or human control. In such cases, some may point in a "good" direction while other may show the reverse trends. In essence, a compromise may be needed that is "acceptable" and not necessarily "best" or even "optimum". Reaching a compromise solution is not helped by a plethora of indicators, even if each of them is well-defined and important for each individual aspect of system performance.

A possible approach to this conundrum is to search for a single unifying metrics of sustainability. We propose a metric applicable to physical sustainability. The term “physical sustainability” is meant to encompass all concerns about living within the laws of nature and minimizing the impact on the physical environment. From this perspective, a better definition of sustainability could be based on the concept of energy debt incurred against energy stocks stored earlier or material (mass) flow. In this approach, the changes of energy stock formation and depreciation are directly accounted for, and the time required for the debt repayment (if any) is explicitly specified. For example, windpower is essentially instantly replaced (if the wind continues to blow). Water discharged from a reservoir to generate electricity may be replaced in the next hydrologic year. But if a growing tree is chopped down and used for fuel, the time for its replacement is typically measured in years or decades. Oil, on the other hand, was created on a geological time scale and, for all practical purposes, is irreplaceable. Thus, the energy debt due occurred from using a tree as an energy source may be repaid within one human generation while burned oil or coal will remain as a debt.

Strictly speaking, energy consumption is a misnomer since the first law of thermodynamics asserts that energy is neither lost nor gained. What is commonly understood under the term of “energy consumption” is utilization of “high quality” energy. This idea was quantified through the idea of exergy proposed by several authors and formalized by Szargut et al[9]. in 1988. While the material balance or the energetic approach to quantification of human activities have been promoted as indices of “sustainability,” neither of them is theoretically sound nor easy to use. Each considers only one side of the issue and does not allow for evaluation of alternatives where higher energy use could be offset by lower consumption of materials and *vice versa*. Moreover, a simple material balance does not account for differences in the ways the materials are used and transformed in a production and consumption process. For example, the material balance approach will not differentiate between one process that produces mixed and diluted by-products (waste) and another that generates separate and concentrated streams of the same by-products. Yet in the second case, any further by-product utilization or re-use is much easier than in the first case. Even if these by-products or wastes are not currently reused, their containment and mitigation of potential environmental impacts are also easier. In the first case, “dilution is the solution to pollution.”

The essence of physical-chemical transformations and material “dilution” can be captured by entropy. In a simple example, diluting a contaminant stream increases its entropy. This increase may be reversed but is associated with a supply of energy from an extraneous source. Although the notion of entropy dates back to the advances of thermodynamics in the 19th century, it has only recently come of use in the ecological area[10]. Entropy can be defined in the thermodynamical terms following the seminal work of Rudolf Clausius in the 19th century. Another definition of entropy follows the Boltzmann’s approach rooted in the statistical mechanics where it is related to the probability distribution of the micro-states of a system. In this form, the definition of entropy is mathematically identical with that proposed by Shannon in 1949 in the context of the information theory.

Such diverse and yet ultimately equivalent formulations of entropy make it especially appealing for a sustainability analysis since it allows, in principle, to account for various forms of energy (thermal, potential, kinetic) and for transformation of materials (and their dilution or concentration). Therefore, entropy can be used to characterize the changes of both the energy and the matter. In many cases, ecological problems may be related to an entropy increase, for example as a result of transformation of "high quality" energy in fossil fuels to dispersed heat. Many processes generate wastes and yield diluted streams of increased entropy. Such diluted materials can be reconcentrated (and the associated entropy decreased) through the application of energy. Since the Earth's ecosystem is maintained by the flow of energy, it can be shown[11] that the sum of energy flowing through the system and its entropy (multiplied by the temperature) may be a reasonable measure of physical sustainability.

Another interesting link of entropy to system dynamics and its phase space representation was proposed,[12] arguing that entropy can represent a measure of uncertainty about the dynamics of a system. In this treatment, entropy is directly proportional to the volume occupied by a trajectory of a dynamic system in the phase space. According to such an interpretation, sustainable systems would occupy a smaller volume as their trajectories are more restricted and thus would be characterized by smaller entropy.

Conclusions

In this paper, I argued two main points. First is the need for a more clear exposition of moral fundamentals of sustainability. This is a normative problem that defines the values of sustainability in stronger and more specific terms than the somewhat vacuous Brundtland wording. If the concept of sustainability is to be widely accepted, it is necessary to state what is to be sustained and why, especially if modifications (and perhaps some sacrifices) of human behavior are called for.

The second issue deals with the apparent tension between sustainability and development, between maintenance of *status quo* and change. This tension can be resolved and perhaps explained in terms of system dynamics by noticing that a sustainable system may (and most likely will) evolve, often in complex way, but its state variables will remain bounded. This feature can be represented in the phase space by a trajectory occupying a limited volume and perhaps linked to low system entropy. Another definition of entropy, based on thermodynamics, can also lead to a better, more universal definition of physical sustainability.

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1. World Commission on Environment and Development (1987). *Our Common Future.* Oxford University Press: Oxford.

2. For more discussions along these lines see "Poverty of Reason", a brilliantly written book by Wilfred Beckerman, emeritus fellow at Balliol College, Oxford

3. "Walking the Talk" by Charles O. Holliday Jr.(CEO, Du Pont); Stephan Schmidheiny (ANOVA Holdings); Sir Philip Watts (CEO, BP):

4. Briggs, J., Peat, F.D. (1989). Turbulent Mirror. Harper Row, N.Y.

5. Thompson, J.M.T., Stewart, H.B. (1986). Nonlinear dynamics and chaos. Wiley

6. Pascale, R.T., Millemann, M., Gioja, L. (2000). Surfing the edge of chaos. The laws of nature and the laws of business. Crown Business

7. Lorenz, E.N. (1963). Deterministic Nonperiodic Flow. Jour. Atmospheric Sci., 20, 130

8. Urbach, R.M.A. (2000). Footprints of Chaos in the Markets. FT-Prentice Hall

9. Szargut, J.; Morris, D.R.; Steward, F.R.. (1988). *Exergy Analysis of Thermal, Chemical, and Metallurgical Processes*. Hemisphere, New York

10. Rechberger, H.; Brunner, P.H. (2002). A New, Entropy Based Method To Support Waste and Resource Management Decisions. Environmental Science & Technology; 36(4); 809-816.; Singh, V.P.; Fiorentino, M. (1992). *Entropy and Energy Dissipation in Water Resources*. Kluwer, Dordrecht

11. Slawomir W. Hermanowicz, "Entropy and Energy: Toward a Definition of Physical Sustainability" (December 1, 2005). Water Resources Center Archives. Working Papers. Paper swr_v2. http://repositories.cdlib.org/wrca/wp/swr_v2

12. A very readable exposition of this link is in Baranger, Michel. Chaos,Complexity,and Entropy. A physics talk for non-physicists. http://necsi.org/projects/baranger/cce.html http://necsi.org/projects/baranger/cce.pdf. A much more complicated and mathematical treatment is given by Fraser A.M.. (1989) Information and Entropy in Strange Attractors. IEEE Transactions on Information Theory, Mar, 1989, V35(n2):245-262