The dialectics of sustainability

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Most approaches to sustainability are rooted in general system thinking. In this framework, linkage patterns are key factors for understanding the dynamics of the systems and whose knowledge is fundamental to search for trajectories that guide our society toward greater sustainability. Nevertheless, multiple linkages do not merely transmit impacts and allow greatly separated components to communicate. They also allow opposites to manifest in their dynamic consequences, and they become the locus for explanation of the whole-and-part relationship. I show here, by using Levins' loop analysis, that these dialectical attributes emerge in the context of sustainability and that they can bring about practical implications.

Introduction

General environmental concern gave rise some decades ago to the emergence of 'sustainable development' as a new paradigm of environmentalism.[1] Under the stimulus of the United Nations Conference on Environment and Development, held in Rio de Janeiro in 1992, sustainability became a key term that populated political agendas, activist programs, and scientific enterprises. Since that summit, the concept of 'sustainability' has become widely accepted as a uniting and purposeful focus for the twenty-first century. It was the new frontier of the environmental debate.

The way sustainability and sustainable development have been approached in the effort to make these concepts operational is inherently systemic. Official documents as well as position and research papers largely embrace this point of view (Azapagić 2003, Gallopin 2003, Fiksel 2006, Batanovic et al. 2011, Pappas 2012). The 107th Plenary Session of the Committee of the Regions of the European Union reaffirmed the position of the EU in respect to sustainability, positing that *"a holistic approach is a comprehensive approach that provides complex answers both to questions of environmental protection and to the social and economic problems of cities, which is why the concept of the sustainable city has to be about more than just environmental protection. In the future, urban development will only be possible if a holistic and sustainable approach is followed"* (Commission of the European Communities 2001).

Some years ago I took part in a conference on environmental monitoring and indicators. In the attempt to link the theme of the congress with that of sustainable development, it was posited that coping with the whole system dimension represents the new challenge for the development of effective sustainability monitoring systems (Bodini 2012). According to this, any approach to sustainability should imply:

- the use of systemic models both as conceptual bases and description of real systems;
- the development of holistic measurement concepts as prerequisites for a new generation of indicators;
- that focal goals and targets that determine the evaluation procedures referring to the indicator systems have to be holistic.

Pappas (2012), while advocating for the use of a systems theory approach to thinking about sustainability problems, clarifies what sustainability should mean: *"A sustainable society possesses the ability to survive and prosper, not just with respect to environmental resources, but also with respect to quality of life as it pertains to social, economic, technical, and individual contexts, and especially the values and conditions that promote continued human prosperity and growth (e.g., opportunity, economy, privacy, community, the arts, education, and health). A sustainable society meets these needs simultaneously, and in the context of human respect and the ability to negotiate differences without violence."*

The concept embodied in this statement as well as in other definitions that root in the system level thinking (Gallopin et al. 1989) is clearly goal-seeking; it promises generalized benefits and, as such, it is at best visionary. The idea of balance and harmony that often inspires system thinking led to define a sustainable society as one that provides permanent prosperity within the biophysical constraints of the real world in a way that is fair and equitable to all of humanity, to other species, and to future generations.

Although it is recognized that maximization of all "utility goals" is not possible and trade-offs are unavoidable (Costanza 2000, Harris 2003) systemic approaches insist on the need to trace interlinkages and connections between system components to entirely capture the complexity of human and ecological systems. As Gallopin (1994) reaffirmed *"development projects fail for many reasons, most of them reflecting some property or system behavior that was not taken into account."* Failure thus would come about because analysis is conducted over incomplete systems and crucial processes are left out.

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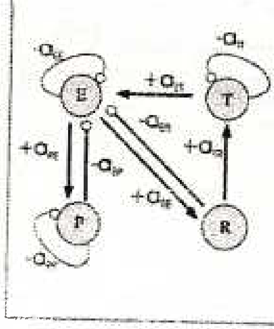
[1] It was in October 1987 that the Brundtland Commission officially dissolved a document also known as the Brundtland Report in which the meaning of the term "Sustainable Development" was first introduced.

Attention is not paid, however, to the dialectical nature of human and environmental systems, which are governed by opposite interests and goals and that bring about contradictions at various levels. Because of this the road map to sustainability is contradictory in itself and far from being a smooth pathway. In what follows I will make use of two simple case studies investigated through Levins' loop analysis to discuss how dialectics pervades the sustainability question. In particular, the two examples serve to highlight two basic principles of the dialectical thinking: the unity and struggle of opposites and the part-whole relationship in environmental systems.

Case 1. A strategy for sustainable management

The system of interest is represented by the signed digraph of Figure 1. It relates to the management of natural reserves and recreation areas from the point of view of a local public administration.



First criterion for stability $F_k < 0$ $k = 1, 2, 3$

$$F_1 = -a_{EE} - a_{PP} - a_{TT} < 0$$
$$F_2 = -a_{EE}a_{PP} - a_{EE}a_{TT} - a_{PP}a_{TT} - a_{EP}a_{PE} - a_{RE}a_{ER} < 0$$
$$F_3 = -a_{RE}a_{ER}a_{PP} - a_{EP}a_{PE}a_{TT} - a_{RE}a_{ER}a_{TT} + a_{RE}a_{TR}a_{ET} - a_{EE}a_{PP}a_{TT} = ?$$
$$F_4 = -a_{RE}a_{ER}a_{TT}a_{PP} + a_{RE}a_{TR}a_{ET}a_{PP} = ?$$

Second criterion for stability $F_1F_2 + F_3 > 0$

$$-a_{EE}^2a_{PP} - a_{EE}^2a_{TT} + 3a_{PP}a_{TT}a_{EE} - a_{EP}a_{PE}a_{EE} + a_{RE}a_{ER}a_{EE} + a_{PP}^2a_{EE} +$$
$$+ a_{PP}^2a_{TT} + a_{EP}a_{PE}a_{PP} + a_{RE}a_{ER}a_{PP} + a_{TT}^2a_{EE} + a_{TT}^2a_{PP} + a_{EP}a_{PE}a_{TT} +$$
$$+ a_{RE}a_{ER}a_{TT} - a_{RE}a_{ER}a_{PP} - a_{EP}a_{PE}a_{TT} - a_{RE}a_{ER}a_{TT} + a_{RE}a_{TR}a_{ET} =$$
$$= +a_{EE}^2a_{PP} + a_{EE}^2a_{TT} + 3a_{PP}a_{TT}a_{EE} + a_{EP}a_{PE}a_{EE} + a_{RE}a_{ER}a_{EE} +$$
$$+ a_{PP}^2a_{EE} + a_{PP}^2a_{TT} + a_{EP}a_{PE}a_{PP} + a_{TT}^2a_{EE} + a_{TT}^2a_{PP} + a_{RE}a_{TR}a_{ET} > 0$$

Figure 1. Signed-digraph that depicts main relationships between system variables that are: economy (E), local tourism (T), protection effort (P), and recreation (R), and calculation of the Routh-Hurwitz criteria for stability. (From Bodini et al. 2007)

The idea behind the model is that of a system in which local economy sustains recreation programs (i.e. creation of areas for local tourism) and protection programs (i.e. the creation of small natural reserves) in the territory of a small municipality. First key variables are identified: local economy (E)—the stock of financial resources available to the public administration; local tourism (T), as total number of visitors; protection effort (P), as funds for maintaining natural reserves; recreation (R)—economic resources used to realize and improve recreation areas and related services. According to Levins' loop analysis (Levins 1974) arrows stand for positive relations, and circle head links for negative ones. Both R and P consume the main resource E; R in turn exerts a positive effect on the number of visitors (T). Tourism generates economic return for the public administration and is depicted as beneficial for local economy (arrow connecting T to E). Same positive effect on T is not considered for P because access to natural reserves should be prohibited.

There are links whose meaning is not of immediate or intuitive comprehension. A self-link, a link connecting one variable with itself, characterizes all the nodes but R. The negative self-link on E tells us that this variable is self-damped. This is due to a continuous supply of money from the taxation system which guarantees the economy of the public administration (see Puccia and Levins 1986 for a detailed discussion about the self-damping). The self-loop on P considers the reluctance of local administrators to increase expenditure for protecting nature. Communities often criticize the use of financial resources to create natural parks or reserves; so the more resources are dedicated to these programs the higher the opposition of people is. This, in turn, leads politicians to spend progressively less money in these programs. Thus coefficient (a_{PP}) takes into account this attitude shown by administrators under the pressure of the public opinion. It is very hard to quantify, although its effect is very real. A typical case in which qualitative models are appropriate tools of investigation (Puccia and Levins 1986).

R is not limited by its growth. In the context of non-consumptive wildlife-oriented recreation, as the system proceeds toward more mature stages, resource requirement may increase as well (Duffus and Dearden 1990). In fact, whereas at earlier stages resources are needed to create infrastructures, later on they are used up to improve services and facilities. The number of visitors (T) is self-damped because crowding discourages more tourists to visit the sites.

Although it is clear that sustainability is not simply a question of stability, and does not relate to stability in a simple way, analyzing the system for its stability can be helpful as it reveals critical aspects that may affect its persistence of a management plan and, consequently, its sustainability.

Levins' loop analysis considers circuits formed by links and their associated feedbacks to study model stability. A circuit is a series of links that starts at one node and returns to it without crossing intermediate variables more than once. Circuits can be identified on the graph by following the direction of links. They constitute different levels of feedback depending on the number of variables they involve. For example, all the self-damping terms belong to the first level of feedback as each of them involves only one variable. There are as many levels of feedbacks as variables in the system. In the graph of Figure 1 there are four levels of feedback: F_1, F_2, F_3, F_4. Circuits linking a certain number of variables can be combined to form an upper-level feedback (i.e., the three self-damping can be combined to form a feedback in F_3). They are called disjunct loops. Associated with any circuit there is a feedback. It can be positive or negative, and its sign is obtained by multiplying the sign of the coefficients a_{ij} that are attached to the links. The result must be further multiplied by $(-1)^{m+1}$ where m is the number of disjunct loops that enter in the feedback.

The first condition for stability is that all the levels of feedback must be negative $F_k < 0, \forall\, k$. Yet negative feedbacks produced by longer loops must not be too strong when compared to those from shorter ones (second stability condition). For a four-variable model this condition corresponds to verify the inequality $F_1 \times F_2 + F_3 > 0$

Computing the two conditions for stability yields the outcomes shown in Figure 1. In this model, the second condition for stability is met; the first condition is not verified because the sign of F_3 and F_4 remains ambiguous. Consider the latter. The negative term is made of the two-node loop $[E\ o \rightarrow R]$ $(-a_{RE}a_{ER})$, the self-damping on local tourism $(-a_{TT})$ and on protection$(-a_{PP})$. This feedback must counteract the positive term, produced by the three-node loop $[E \rightarrow R \rightarrow T]$, and the self-damping on P. Because the two feedbacks share two links, namely the beneficial effect from E to R and the self-damping on P, after algebraically rearranging the terms (see Figure 2) we can obtain that the system may be stable if $-a_{ER}a_{TT} + a_{TR}a_{ET} < 0$.

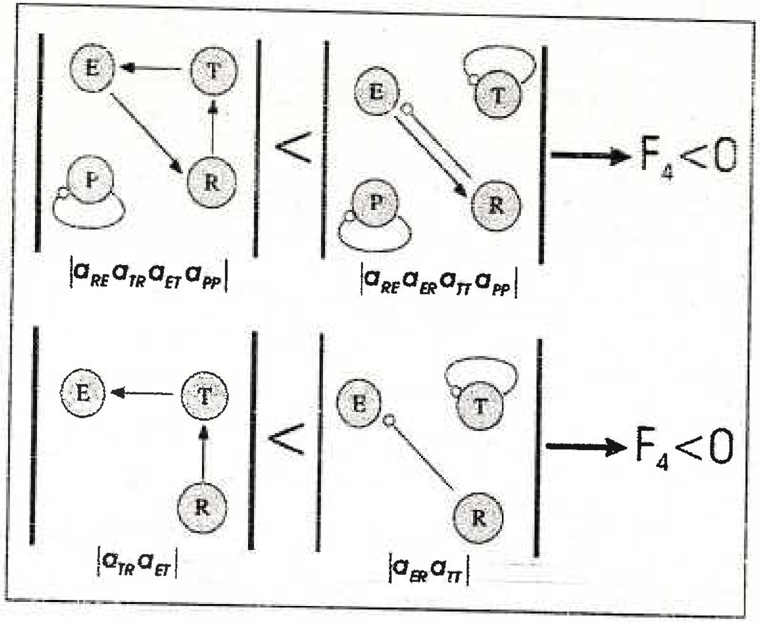


Figure 2. Graphic representation of the condition for stability for the model of Figure 1. (From Bodini et al. 2012)

The attractiveness of recreation areas combined with the economic return due to tourism must be smaller than consumption of the economic resource by recreation programs and the limitation on the number of tourists. Despite the possibility to quantify the links and assess their relative importance on an economic basis, this result suggests if the plan is conceived so as to maximizing the economic return, which on the other hand is the most common attitude, the risk of instability gets greater and the sustainability of the whole plan becomes at risk.

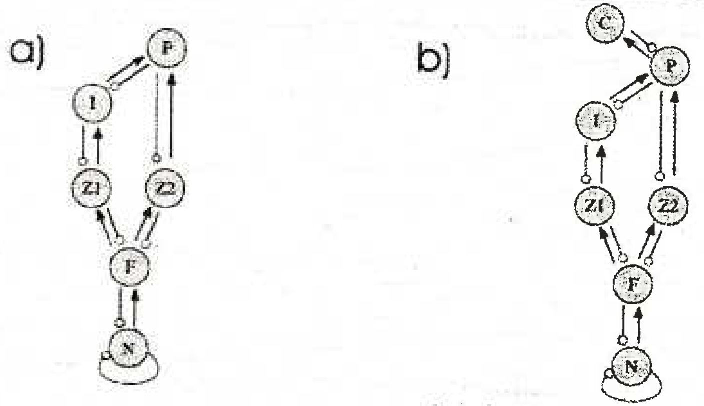
If maximization of economic return in the short period is pursued, it may lead to degradation of the sites (because of crowding), which soon will lose their attractiveness, further reducing the number of tourists and lowering the economic return. If benefit is to be maintained in the long term, as any sustainable policy should pursue, a parsimonious approach to economic return should be taken. Thus the need of maximizing profit, as required in our society, struggles and interferes with the need of implementing a self-sufficient and economically sustainable plan. A typical case of "unity and struggle of opposites," which emerges from the stability analysis.

Case 2. Part-whole relationships in environmental assessment

Environmental assessment is internationally recognized as a key tool to guide us on a path to sustainable development (Cashmore et al. 2007). By predicting environmental, economic and social adverse consequences of projects and plans before they arise, assessment can in principle orient decision-making toward more sustainable practices (Weaver et al. 2008). Whether environmental assessment can effectively contribute in this direction depends on the capability to predict how ecosystems respond to impacts (Binder et al. 2013, Bowd et al. 2015).

In impact assessment we are interested in predicting consequences on single components (i.e. the abundance of a rare species) as well as at the whole system (i.e. the resilience of an ecosystem) and so we are required to go back and forth from parts to whole. In this framework the way parts and whole reciprocally determine each other is crucial to understand how systems respond to impact and take actions.

Suppose that a park administration decides to build a tourist center inside the protected area that is under its jurisdiction. However, it needs to choose between two different locations that are both very attractive because of the presence of two lakes (one in each site) that provide many opportunities for recreation. Decision on which site should host the tourist center has to be taken following impact assessment, so that negative effects are minimized and possibly positive effects are enhanced. Let us assume that the administration is particularly concerned with adverse effects on lake biological communities. A preliminary assessment can be conducted analyzing the signed digraphs that describe the two communities and that are presented in Figure 3.



	N	F	Z1	Z2	I	P
N	?	+	+	-	+	+
F	-	+	+	-	+	+
Z1	-	+	+	-	+	+
Z2	+	-	?	-	+	+
I	-	+	?	-	+	+
P	-	+	+	-	+	+

	N	F	Z1	Z2	I	P	C
N	+	0	0	+	0	0	+
F	0	0	0	+	0	0	+
Z1	0	0	0	0	+	+	+
Z2	+	-	0	+	-	-	?
I	0	0	-	+	0	0	+
P	0	0	0	0	0	0	+
C	+	-	-	+	-	-	+

Figure 3. Signed digraphs depicting two lake ecosystems without (a) and with (b) top predator (C). Below each model the table of prediction is given. Keys are: N, inorganic nutrients; F, phytoplankton; Z1 small bodied zooplankton; Z2, large bodied zooplankton; I, invertebrate predator; P, planktivorous fish; C, predatory fish.

Each model is accompanied by its table of predictions which summarizes all the expected changes in the abundance of the column variables when impacts affect the rate of change of the row variables. The table is conventionally obtained considering positive variations (increased rate of change). In general (see details in Puccia and Levins 1986, Dambacher 2003) the sign of the effect (which predicts the direction of change in the equilibrium level of the variable, as number of individuals, biomass and so forth) is the sign of the initial impact (positive or negative depending on whether the rate of change of the target variable increases or decreases because of the parameter change) times the sign of the path to the variable of interest, multiplied by the sign of the feedback of the rest of the system not included in the path (complementary subsystem), and then divided by the feedback of the whole system.

The communities show the same composition in species but model 3b has a top predator (C) that lacks in model 3a. Thus there is a slight structural difference that characterizes the two communities; nevertheless from the tables of predictions one knows that the two systems show completely different behavior in terms of response to external impacts. Most entries in table 3b are zero, while in table 3a all the coefficients are non-zero. Given that a null value stands for no change expected in the abundance of the variable, we can conclude that the system represented in Figure 3b possesses greater resistance to external impact producing parameter changes than its twin lake (Model 3a). This latter is not resistant at all: all the populations are expected to change in response to impacts entering anywhere in the system. The presence of a single variable (C) positioned as satellite variable for P in the network (Puccia and Levins 1986) modifies the patterns of response of all the other variables to external impacts and make the whole system more resistant that it is without the predator.

From the table of predictions we can grasp that C is the only variable whose abundance is expected to change for any impact that may enter the system (no zero in its column). So it becomes an indicator of changing conditions for the system, a property that C acquired because it is part of that specific whole. Also, only inputs that enter the system through it can modify the level of all the variables in the community. It follows that C becomes now a species that deserves particular attention, no matter if it carries a conservation value in itself. C protects the system from the effects of variability but at the same time makes it vulnerable to its own changes.

The way C modifies the response of the system to external impacts has strong implications for the management because our perception of cause and effects relationships is confounded. It is well known that eutrophication is a diffuse menace to biodiversity and algal blooms are caused by an excess input of inorganic nutrients into water ecosystems. To avoid the disruption of ecosystem mechanisms with fatal consequences on biodiversity, early signs of eutrophication should be detected (Bondavalli et al. 2006). The most obvious surveillance strategy for early warning detection is monitoring algae abundance, but its efficacy may be defied by the network. In model 3b, in fact, an excess input of nutrients is predicted not to change the abundance of phytoplankton (first row, second column)[2]. On the other hand if

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[2] This prediction is not unrealistic. It has been observed (Jeppesen et al. 1991) in fact that system continuously added with inorganic nutrients may absorb this input without any apparent change. This may continue until a certain threshold is reached when any further addition of nutrient would shift the trophic state to irreversible eutrophy. But this catastrophic change cannot be described in a simple way using the moving equilibrium approach.

an increase in algae abundance would be detected, commonsense attitude would immediately assign this effect to an increased input of nutrients and a management action to keep this variable in check would be called for. However model 3b tells us that an increase in phytoplankton (F, in the graph) would occur only for parameter changes entering the system through C and Z2 (second column, fourth and last row) and any intervention to curb nutrient input to the lake would be ineffective. Without a clue about the way C modifies the pattern of response of the other variables to external impacts, interventions conceived to anticipate, reduce or mitigate adverse effects may fail, and the trajectory toward sustainability reverted. This case, in its simplicity, offers a simple picture of how the reciprocal determination of parts and whole in an ecosystem can have practical implications.

Concluding remarks

After having shown in a very simple and, above all, philosophically inadequate way that certain critical aspects of dialectics apply also in the context of sustainability, a question comes to my mind: does dialectics really matter? In other words, is it important whether or not a planner or a practitioner or a decision maker recognizes that dialectics pervades his or her enterprise? On the other hand the use of signed digraphs as predictive tools is not precluded to those who are not interested in the philosophy of science! So what? In the field of environmental sciences and management we are experiencing a great contradiction: never in the past we had as many tools at disposal to predict and monitor the environment as we have today; similarly, the number and type of enforced regulations that nowadays curb human activity is unprecedented. Nevertheless the environment, human health, and biodiversity are degrading at a faster rate. This contradiction is never taken into account seriously. It is not even acknowledged. Ever grater problems call for more stringent regulations in a vicious circular path that allows polluters and regulators to prosper and reinforce reciprocally although they are in opposition one another. According to this I think that sustainability cannot be achieved by asking how much water we can withdraw from a river before we jeopardize its ecological functions or how much sand or gravel we can extract from a river bank before flooding risk increases too much. The real question about sustainability is how to maintain the identity of the riverine habitat as a whole. Recognizing that this is inherently dialectical may help.

References

Azapagic, A. (2003). "Systems approach to corporate sustainability: A general management framework." *Process Safety and Environmental Protection* 81: 303-316.

Batanović, V., S. Guberinić, and R. Petrović (2011). "System theoretic approach to sustainable development problems." *Yugoslavian Journal of Operations Research* 21: 1-10.

Binder, C. R., J. Hinkel, P. W. G. Bots, and C. Pahl-Wostl (2013). "Comparison of frameworks for analyzing social-ecological systems." *Ecology and Society* 18: 26.

Bodini, A. (2012). "Building a systemic environmental monitoring and indicators for sustainability: What has the ecological network approach to offer?" *Ecological Indicators* 15: 140-148.

Bondavalli, C., A. Bodini, G. Rossetti, and S. Allesina (2006). "Detecting stress at the whole ecosystem level. The case of a mountain lake: Lake Santo (Italy)." *Ecosystems* 9: 768-787.

Bowd, R., N. W. Quinn, and D. C. Kotze (2015). "Toward an analytical framework for understanding complex social-ecological systems when conducting environmental impact assessments in South Africa." *Ecology and Society* 20: 41.

Cashmore M., A. Bond, and D. Cobb (2007). "The contribution of environmental assessment to sustainable development: Toward a richer empirical understanding." *Environmental Management* 40: 516-530.

Commissin of the Euroepan Communities (2001). "A Sustainable Europe for a better world: A European Union strategy for sustainable development." Euroepan Union, Brussels.

Costanza, R. (2000). "Visions of alternative (unpredictable) futures and their use in policy analysis." *Conservation Ecology* 4(1): 5.

Dambacher, J. M., H. W. Li, and P. A. Rossignol (2003). "Qualitative predictions in model ecosystems." *Ecological Modelling* 161: 79-93.

Duffus, D. A. and P. Dearden (1990) "Non-consumptive wildlife oriented recreation: a conceptual framework." *Biological Conservation* 53: 213–231.

Fiksel, J. (2006). "Sustainability and resilience: toward a systems approach." *Sustainability: Science Practice & Policy* 2: 14-21.

Gallopín, G. C. (1994). "Impoverishment and sustainable development: A system approach." Winnipeg, Canada: International Institute for Sustainable Development.

______ (2003). *A Systems Approach to Sustainability and Sustainable Development.* Santiago, Chile: United Nations.

Gallopín, G. C., P. Gutman and H. Maletta. (1989). "Global impoverishment, sustainable development and the environment. A conceptual approach." *International Social Science Journal* 121: 375–397.

Harris, J. M. (2003). "Sustainability and sustainable development," in A. C. Aitken (Ed.), *International Society for Ecological Economics Encyclopedia of Ecological Economics*. https://www.researchgate.net/publication/237398200_ Sustainability _and_Sustainable_Development. Retrieved August 14, 2018.

Jeppesen E., P. Kristensen, J. P. Jensen, M. Søndergaard, E. Mortensen, and T. Lauridsen (1991). "Recovery resilience following a reduction in external phosphorous loading of shallow, eutrophic Danish lakes: duration, regulating factors and methods for overcoming resilience." *Memorie Istituto Italiano Idrobiologia* 48: 127-148.

Levins, R. (1974). "The qualitative analysis of partially specified systems." *Annals of the New York Academy of Sciences* 231: 123-138.

Pappas, E. (2012). "A new systems approach to sustainability: University responsibility for teaching sustainability in contexts." *Journal of Sustainability Education* 3: 1-18.

Puccia, C., and R. Levins (1986). *Qualitative Modeling of Complex Systems*. Harvard University Press, Cambridge, MA.

Weaver, A., J. Pope, A. Morrison-Saunders, and P. Lochner (2008). "Contributing to sustainability as an environmental impact assessment practitioner." *Impact Assessment and Project Appraisal* 26: 91-98.