Principles of Human-Environment Systems (HES) Research

Roland W. Scholz

Claudia R. Binder

Principles of Human-Environment Systems (HES) Research

Roland W. Scholz and Claudia R. Binder

Natural and Social Science Interface, Institute for Human Environment Systems. Department of Environmental Sciences, Swiss Federal Institute of Technology Zürich (ETH), Switzerland

Abstract: This paper presents the basic principles, applications, and a methodological discussion of the approach of Human-Environment Systems (HES). In general, HES includes all environmental and technological systems that are relevant for or affected by humans. The basic principles of the HES approach are: (1) human and environmental systems are constructed as complementary systems, (2) a hierarchy of human systems with related environmental systems are considered, (3) environmental systems are modeled in their immediate and delayed dynamic reactions to human action, (4) the behavior of the human system is modeled from a decision theoretic perspective differentiating between goal formation, strategy formation, strategy selection and action, (5) a conceptualization of different types of environmental awareness in each of these three steps can be developed, and finally (6) a distinction is made, with corresponding modeling reflecting this distinction, between primary and secondary feedback loops with respect to human action. We illustrate the principles with an example from bio-waste management. It is shown how the human-environment interaction can be analyzed.

Keywords: Human-environment systems, regulatory mechanisms, feedback mechanisms, interfering regulatory mechanisms, bio-waste management.

1. INTRODUCTION

The investigation of complex environmental systems that are affected by human action is considered a major scientific challenge. This challenge has to overcome both the gap between natural and social sciences and to master modeling on different scales. Thus, there is a need for integrating knowledge from natural and social sciences. Human-environment systems (HES) are defined as the interaction of human systems with corresponding environmental or technological systems.

We provide a process and structure model, which is derived from integrative modeling, system theory, basic cybernetic feedback loop modeling, cognitive sciences, and decision research (Ashby, 1957; Simon, 1957; Scholz, 1987). This process and structure model should allow for investigating regulatory, feedback, and control mechanisms (RFC-mechanisms) in HES. Our motivation is to conceptualize environmentally sensitive regulatory, feedback, and control systems of the anthroposphere. Our goal is to understand the evaluation, transformation, and regulation processes of human systems with respect to environmental and resource systems. This is done when considering a multi-hierarchy level of human systems. The HES approach is considered a framework for the understanding of the mechanisms underlying environmentally sensitive action, for reflecting on interferences among different levels (i.e., the individual and societal level), and for reflecting on different feedback loops or RFC mechanisms that may lead to sustainable action.

1.1 Relationships between human and environmental systems in environmental sciences

The HES approach conceptualizes a mutualism between human and environmental systems. The human and the environmental system are conceived as two different systems that exist in essential dependencies and reciprocal endorsement. The term human systems, meaning social systems ranging from society to individuals (Apostle, 1952), has been used since the time of the ancient Greeks. These systems are supposed to have a memory, language, foresight, consciousness etc. In contrast to the concept of human or social systems, the term environmental systems arose late in the early 19th century (Simpson & Weiner, 1989 p. 315), even though Hippocrates had already dealt with environmental impacts on human health in early medicine in 420 BC.

In the history of environmental sciences at large, the relationship between human ($\boldsymbol{H}$) and environmental ($\boldsymbol{E}$) systems was dealt with from different perspectives. The $\boldsymbol{H \rightarrow E}$ impact chain was initially examined from the human perspective. In the early 18th century, forest engineers investigated how legal or economic restrictions affect the texture of forests agricultural, forest. Resource economics evolved in the early 18th century and focused on the question of how agricultural and forest yields can be sustainably (von Carlowitz, 1732) or most efficiently obtained (Goodwin, 1977). From the environmental research perspective, the $\boldsymbol{H} \rightarrow \boldsymbol{E}$ impact chain has quite a different focus, namely how human activities affect the environment or environmental equilibrium and how these impacts can be mitigated (Wood, 1995, Freedmann, 1995).

There are different ways for the relationship of what we denote as Human and Environmental Systems to be conceptualized.

The GAIA-approach (Lovelock, 1979) "views the earth as a single organism, in which the individual elements coexist in a symbiotic relationship. Internal homeostatic control mechanisms, involving positive and negative feedbacks, maintain an appropriate level of stability." (Kemp, 1998, p.160) GAIA is an example of an integrative, qualitative approach for studying HES. In the GAIA approach the equation $\boldsymbol{H} \cap \boldsymbol{E} = \boldsymbol{H} \cup \boldsymbol{E}$ holds true.

In integrated modeling (Odum, 1997; Holling, 2001) variables from the social system (such as resource availability) and variables from environmental systems (such as economic growth) are considered within one system structure, mutually and functionally related and sometimes even hierarchically related. Integrative modeling starts from coupled systems and provides a quantitative analysis (Bossel, 1998; Carpenter et al., 1999).

The HES approach presented below separates human and environmental systems and studies their mutualism. Note that the concept of environment emerged in the early 19th century, a time when the upcoming industrial age unmistakably revealed the interaction and mutual dependency between these two systems. Mutual dependency, reciprocity, and the $\boldsymbol{H} \leftrightarrow \boldsymbol{E}$ impact chains can be approached from the environmental as well as from the human perspective. The former looks at optimizing environmental quality by integrating human models into ecosystem analysis (Naveh & Lieberman, 1994). The latter investigates the impact of regulatory mechanisms on the state of the environment when taking an anthropogenic perspective (Hammond, et al., 1995).

2. BASIC PRINCIPLES FOR MODELING HES

2.1 Six basic principles

This paper follows an approach, which begins from six basic assumptions from the modeling of HES (Figure 1)

(1) Conceive human and environmental systems as two different, complementary, interrelated systems with human action and "immediate environmental reaction" being part of both systems.

(2) Consider a hierarchy of human systems with related environmental systems.

(3) Construct a 'state of the art' model of the environmental system and its long-term dynamics.

(4) Provide a decision theoretic conceptualization of the human system with the components goal formation, strategy formation, strategy selection and action.

(5) Characterize and conceptualize different types of environmental awareness in each component of (4).

(6) Distinguish and model primary and secondary feedback loops with respect to human action.

We will explain these principles and illuminate the specific contribution of the HES approach.

Principle (1) "departs from approaches that try to understand and predict complex dynamics resulting from endogeneous interactions without any exogeneous interference (human intervention)" (quoted from an anonymous review). The Human species is treated as a separate entity (left part of Figure 1) with complementary environmental systems presented at the right side of the figure. This is done because we have different insight and access to natural and social systems and as we acknowledge that knowledge about these systems is organized in disciplines, which emerged from an understanding of natural and social systems. The links between these systems are, in a first view, the immediate physical impacts or perceivable changes caused by human action, i.e., the felled tree, which might cause an accident at work.

For human systems, *Principle* (2) departs from Miller's (1978) hierarchical levels and distinguishes between the individual, the group, the organization, and society. Of course systems of a smaller scale such as organ, cell, RNA etc. and systems of a higher level such as supranational systems can also be considered. At each hierarchy level specific human – environment relationships and regulatory mechanisms are encountered. As Forman (1995, p. 505) notes, these specific interactions between human end environmental systems are of importance as "… control or regulation mechanisms that produce stability are usually interpreted in terms of hierarchy, …" (Forman, 1995, p. 505) Thus it is a specific challenge for researcher, when considering human action, to construct the appropriate complementary environmental systems.

Within each hierarchy level, insights from sub-disciplines can be integrated into the process and structure modelM. This is particular of interest, if sustainable action is the object of research: “One way to generate more robust foundations for sustainable decision making is to search for integrative theories that combine disciplinary strengths while filling disciplinary gaps.” (Gunderson, Holling, & Ludwig, 2002, p. 8).

Perhaps, to scientists, the ‘state of the art’ request in *Principle* (3) seems to be trivial. The message of this principle, however, is twofold. First it implies that long term predictions, e.g. on species biodiversity, resource availability, changes of resilience etc. are statements on fuzzy and context bound as they include unknown dynamics due to adaptability or general contextual changes. But, second, the ‘state of the art’ attribute also indicates that analysis with the HES approach should refer to the (robust) current body of knowledge but cannot go beyond.

Principle (4) is characteristic for the adopted decision theoretic perspective. We start with intended action or goals and consider human behavior to be functional and purposeful (Brunswik, 1952; Scholz & Tietje, 2002). We distinguish goal formation, strategy formation, and strategy selection. According to a decision theoretic framework, preferences and strategies are the basic components of behavior. In this context we refer to a game theoretic conception of a strategy in extensive games (Osborne & Rubinstein, p. 92). We define a strategy as a complete plan – which the researcher has to construct – that provides a behavioral directive for each situation in the course of goal attainment. The goals establish preference structures that underlie strategy evaluation. The latter, of course also depends on the capability, experiences and constraints of the HES under consideration. The goal systems is conceived a rather stable, situational activated, and based on onto- and phylogenic history (Scholz, 1987 We assume that – at least starting from hierarchy level of the individual upwards – human system can subjectively evaluate the supposed expected utility or gain of a strategy. This stage is called foresight or anticipation.

In Principle (5) we conceptualize environmental awareness. This can be done, for example, on three levels with the level of a) completely ignoring the impacts resulting from action, b) incorporating environmental sensitivity and change, and c) altruistically neglecting oneself and only targeting the benefits for the environment as is partly the case in deep ecology approaches.

The action and the immediate reaction are conceived of as the changes in the HES system resulting from a certain strategy, under given environmental circumstances and constraints. This is the interface, $\boldsymbol{H} \cap \boldsymbol{E}$, between the two systems. The human and the environmental systems are in a physically different state after a human action is performed. A critical issue is what is conceived of as immediate and what is conceived of as a delayed reaction. According to the decision theoretic perspective, an environmental reaction is defined by the episode, period or events that are temporally and at least partly causally related to the consequences of the action. The time period depends on the memory and the environmental model of the human unit. Note that this statement holds both for cell conditioning (Brembs et al., 2002) as well as for governmental environmental protection programs.

Principle (6) differentiates between two types of post-decisional evaluation. One takes place temporally proximally to the environmental reaction and can be conceived of as learning by primary feedback. Another post decisional evaluation is considered to take place temporally and spatially proximally to the environmental reaction. However, human action can result in side effects, i.e. unintended dynamics and dislocated reaction, which alter the environmental system in a favorable or unfavorable manner and which can show rebound effects. Side effects are often delayed (Venix, 1996) or dislocated as, from the human system perspective, they are not directly related to the perceived environmental reaction. These temporal (or spatial) delays (dislocations) in the environmental system are considered to be second order feedback to the human system, as the individual will notice the effects later (or at other places). A critical question is whether, in which way (i.e. by which “algorithms”), and when a delayed or dislocated impact is evaluated. If we follow the principles of bounded rationality, optimizing primary and secondary learning depends (i) on economically sampling of appropriate cues or evidences related to action, (ii) on setting suitable and robust time and spatial boundaries, and (iii) efficiently changing goal formation, strategy selection, and strategy evaluation.

Of particular interest is the fact that human action at one level of the human system, may lead to environmental impacts, which in turn provide feedback to the human system at a level different to the one of action. That is, feedback loops do not necessarily occur within one scale or level of the human system, but across levels. In addition, the human systems might differ in their goals, and strategies, generating interfering actions and environmental feedbacks. For example, fast financial success in a market can trigger slow, but deep changes in structures on another level. “Thus modern economists are frustrated in their attempts to understand the interactions between fast- and slow moving variables that create emergent dynamics.” (Gunderson et al. 2002, p. 8)

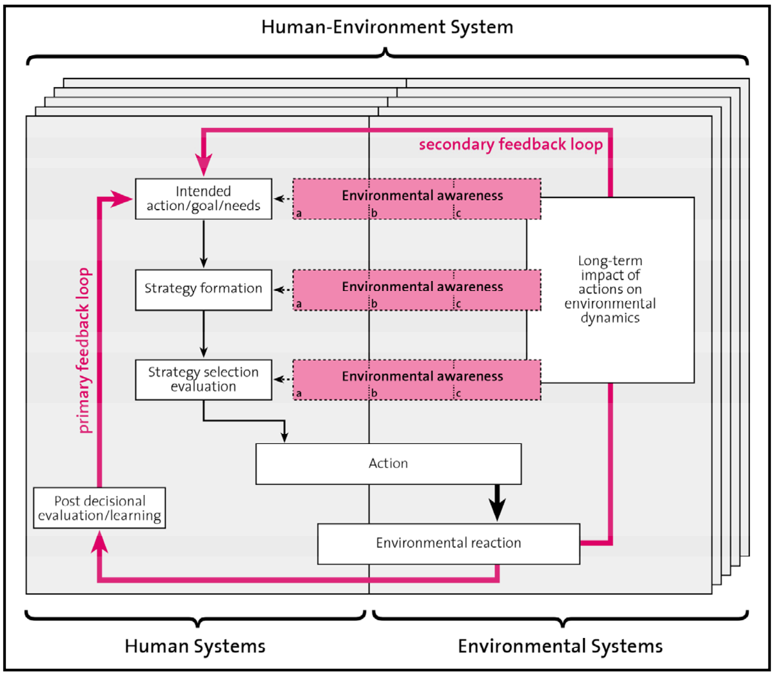

Figure 1. A structure - process model of HES.

2.3 The concept of regulatory, feedback and control (RFC-) mechanisms

One peculiarity of the HES model is that it challenges environmental research to investigate RFC-mechanisms, in particular, adaptive cycles that describe real and/or sustainable behavior. The critical issue in this is the appropriate balance between change and stability. According to evolutionary approaches homeostasis and stationary, dynamic or evolutionary stable equilibria are of specific interest. From ecosystem sciences and theories of development, however, we have learnt that adaptive cycles pass stages such as release, reorganization, exploitation and conservation (Holling & Gunderson. 2001). In principle, these ideas and other assumptions (e.g., those related to chaos) can be linked to the development by stages (Piaget, 1953).

Let us illustrate the idea of RFC-mechanism in HES by considering the case of formation of a biofuel company. A crucial step of HES research would be to determine the key actors (e.g. the technology pioneer or the head of a credit department of a large bank) and their drivers (i.e. goals). This can be done based on decision psychology (see Scholz et al 2003). The environmental changes can be in a first approach modeled by the physical and financial flows with their environmental impacts. Then, a sophisticated HES model would describe a primary feedback loop illustrating both the impacts would be of certain strategies (i.e. business plans of the pioneer; credit rating and portfolio considerations of the credit officer) and the short-term impacts on the material fluxes and its environmental impacts. The secondary feedback loop would include insight into environmental quality (from the green side) and market dynamics (including material and money flows) from the bankers' side.

3. THE EXAMPLE OF BIOWASTE MANAGEMENT

In the following, we report the application of the model presented above for the case of bio-waste management in Zurich (see Lang et al., 2003). We present an ex-post case analysis. We begin by studying the history of decision-making in the human system until the environmental reaction was obtained. In order to do so we will study the change in the system between the years 1995 and 2002. The regulatory level taken is that of the canton of Zurich, which felt uneasy with the resource depletion of organic waste by incineration.

3.1 Methods and data

Data were obtained from the environmental agency in Zurich (AWEL), which has been gathering data on the quantity and quality of bio-waste material since 1991.

To model the environmental system (i.e., environmental reaction), we extended the method of Material Flux Analysis (MFA; Baccini and Bader, 1996) to include agents in the system analysis so that the environmental system can be linked to the human system (Binder et al., 2004). To investigate the human system we used literature analysis, oral history and expert interviews.

Utilizing the case study methodology, the impacts and underlying rationale of the development were reconstructed and the key agents in the process of technology implementation and their operations were identified. The methodology for this proceeding is described in Scholz & Tietje, 2003; pp. 84; Laws et al. 2002; Binder et al., 2004).

3.2 System analysis

Figure 2 presents the system analysis for bio-waste management in the canton of Zurich. The system border is the canton of Zurich. The system is composed of 5 processes and 10 flows. There are three main bio-waste delivery processes, i.e., municipal collection, gardeners, and industry. Separately collected bio-waste can be treated in two ways: composting or anaerobic digestion, which are considered as action alternatives that are components of mixed strategies (i.e., an allocation of fractions treated with these two modes of waste processing; for the sake of simplicity, incineration is not considered see Schleiss and Scholz, 2002). The main agents are directly related to the processes. Additional agents are municipalities, the canton of Zurich and the State (i.e., Switzerland).

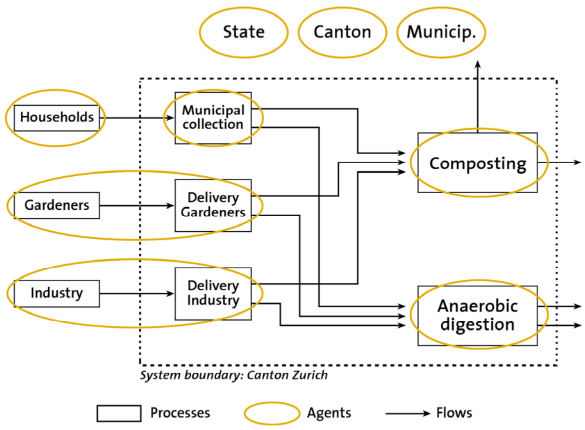

Figure 2. System analysis for bio-waste management in the canton of Zürich (Adapted from Lang et al., 2003)

3.3 Results

From 1995 to 2002 the total amount of biowaste separately collected and treated (and not being incinerated) increased by 37%, which corresponds to 36'500 tons (Lang et al., 2003). The largest relative increase was found for industries followed by gardeners and municipalities. The latter had already had a high collection and delivery rate in 1995 whereas industries had not separately collected their bio-waste before (Table 1). Nearly all the newly collected bio-waste was treated by anaerobic digestion.

Table 1. Amount of bio-waste delivered by the main agents in 1995 and 2001 in t/year (Source: Lang et al., 2003)[a]

Year	Municipalities	Gardeners	Industry
1995	51'000	27'500	1'40(
2001	70'000	40'000	10'50(

a: Rounded values

To explain the development in bio-waste management we present three major stages and related impact factors.

First, the anaerobic digestion technology improved from in the mid of the 1990ies so that it became an economic and ecologically feasible alternative to composting for treating bio-waste. This development was initiated by some pioneers in the field of green technologies (i.e., KOMPOGAS).

Second, for Swiss industries (including large retailers such as MIGROS, which has more than 1/3 of the market share), environmental impacts became increasingly important, with environmental performance becoming more and more of an issue of prestige where the goal is to demonstrate that they run an ecologically and socially responsible business. Therefore, the option of delivering bio-waste for anaerobic digestion and utilizing the fuel for driving their business trucks seemed a good option for showing their commitment towards utilizing "clean energy".

Third, for municipalities it was not always easy to have a well managed composting plant, thus, the plants provided severe odor emissions, which led to complaints within the population. Thus, a less odor intensive treatment seemed to be an appropriate solution (Lang et al., forthcoming).

Finally, Switzerland has signed the Kyoto protocol and committed itself to reduce the CO2 emissions. Given the decentralized structure in Switzerland, the canton Zurich saw a possibility to reduce CO2 emission by fostering biogas production. Thus, it issued the article 12a of the Zurich energy law, which became effective in January 1996. This article states that if it is technically and economically viable "all compostable wastes, which cannot be composted locally, have to be processed to marketable goods in central facilities utilizing their energy-potential"[1].

Thus, the combination of several goals at completely different hierarchical levels led to the observed environmental reaction of an increase in the collection of bio-waste and consequent treatment in anaerobic digestion plants. The feedback at all levels was visible as the share of anaerobic digestion increased and is likely to grow further. This example, however, clearly shows, that processes and change within HES have to be studied by including not only the physical flows or the social perspective. Rather a combination and integration of these analyses within a concise framework of the process structure model allows for a better understanding of the system and might support transition processes in these systems.

4. DISCUSSION

4.1 Current research with HES

The HES approach is currently being used to organize a new, medium-scale institute with an identical name at the ETH Zurich. The focus on environmental decision-making is dominant in this institute. In HES research, at present, the case study approach is dominant. Apart from case studies on technology breakthrough, historical case studies, e.g. on the mastership of cholera and pest

[1] Original German wording: "Kompostierbare Abfälle, die nicht dezentral kompostiert werden können, sind unter Ausschöpfung des Energiepotentials in zentralen Anlagen zu marktfähigen Produkten zu verwerten, soweit dies technisch und wirtschaftlich möglich ist." (1983, §12a)

control were carried out as they ideally allow the examination of interfering regulatory systems. However, in principle, psychological experiments can also be carried out so long as the environmental dynamics are simulated with appropriate computer programs.

4.2 Critical issues of HES research

HES research is under construction. The following four challenges deserve special attention:

- How can reconstructions of human decision making with the HES framework be validated?
- [2]In which way can we construct appropriate "secondary feedback loops"? How can we show that systems become stabilized or system transformations become optimized if secondary, long-term dynamics is taken into account?
- What role can RFC-mechanisms play in sustainability management?
- Is decision research (including game theory and risk analysis), with its conception of games against nature, not only a language but also a tool for integrating knowledge and overcoming both the gaps between social and natural sciences and those between theory and practice?

5. CONCLUSIONS

We presented a process structure model that allows for studying adaptation and development processes within Human-Environment systems. This model divides the human and the environment system, providing so the basis for integrating disciplinary knowledge within one framework. Therefore, complex systems consisting of interactions among several agents can be understood and transition processes initiated.

6. ACKNOWLEDGEMENTS

The authors wish to thank an anonymous reviewer for excellent remarks, Daniel Lang for research cooperation and Peter Loukopoulos for assistance in the editing.

7. REFERENCES

Apostle, H. G., 1952. *Aristotle's philosophy of mathematics*. Chicago: Chicago University Press.

Ashby, W.R., 1956, *An Introduction to Cybernetics*. John Wiley, New York.

Baccini, P. & Bader, H.-P., 1996. *Regionaler Stoffhaushalt, Erfassung, Bewertung und Steuerung*, Heidelberg: Spektrum.

Brembs et al., 2002. Operant reward learning in aplysia: neuronal correlates and mechanisms, *Science* 296: 1706-1709

Bossel, H., 1998. *Earth at a crossroads: Path to a sustainable future*. Cambridge: Cambridge University Press.

Brunswik, E., 1952. *The conceptual framework of psychology*. Chicago: University of Chicago Press.

von Carlowitz H. C., 1732. *Sylvicultura oeconomica oder hausswirthliche Nachricht und naturmässige Anweisung zur wilden Baum-Zucht*. Leipzig: bey Johann Friedrich Braunssel. Erben.

Binder C.R., Hofer C., Wiek A., and Scholz R.W. Transition towards improved regional wood flow by integrating material flux analysis with agent analysis: the case of Appenzell Ausserrhoden, Switzerland, *Ecological Economics*, Vol 49/1 pp 1-17, 2004.

Carpenter, S., Brock, W., & Hanson, P., 1999. Ecological and social dynamics in simple models of ecosystem managment. *Conservation Ecology*, 3(2):pp. 351-360.

Goodwin, J.W., 1977. *Agricultural economics*. Reston: Reston.

Gunderson, L.H. & Holling, C.S., & Ludwig, D., 2002. In quest of a theory of adaptive change. Gunderson, L.H. & Holling, C.S.: *Panarchy. Understanding transformations in human and natural systems* (pp.3-24). Washington: Island Press.

Hammond, A., Adriaanse, A., Rodenburg, E., Bryant, D., & Woodward, R., 1995. Environmental indicators: A systematic approach to measuring and reporting on environmental policy performance in the context of sustainable development. Washington: World Resources Institute.

1983. Energiegesetz [Energy law] (Stand am 1. Juli 2002). Pages 5 *in*.

Holling, C.S., 2001. Understanding the Complexity of Economic, Ecological, and Social Systems. *Ecosystems, 4*, 390 - 405.

Kemp, D., 1998. *The environment dictionary. London*: Routledge.

Lang D.J., Binder C.R., Stäubli B., and Scholz R. W., 2003, Optimization of waste management systems by integrating material fluxes, agents and regulatory mechanisms – The case of bio-waste. Paper presented at *Environment 2010: Situation and Perspectives for the European Union*, Porto, Portugal, May 6-10, 2003,

Laws, D., Scholz, R.W., Shiroyama, H., Susskind, L., Suzuki, T. & Weber, O., 2002. *Expert views on sustainability and technology implementation*.

Miller, G. A. (1978). Living systems. New York: McGraw-Hill.

Naveh, Z., & Liebermann, A. S., 1994. *Landscape ecology: Theory and application* (2nd ed.). New York: Springer.

Odum, E. P., 1997, *Ecology: a bridge between science and society*. Sunderland, MA : Sinauer.

Osborne, M.J. & Rubinstein, A., 1994. *A course in game theory*. Cambridge: MIT Press.

Piaget, J., 1953. *The origin of intelligence in the child.* Londin: Routledge & Kegan.

Schleiss, K. & Scholz, R. W., 2001. Alternativen der Kompostbewirtschaftung. *Müll und Abfall* , 79-82.

Scholz, R. W., 1987. *Cognitive strategies in stochastic thinking*. Dordrecht: Reidel.

Scholz, R.W., Mieg, H.,A. & Weber, O., 2003. Wirtschaftliche und organisationale Entscheidungen, In: Auhagen, A.E., & Bierhoff, H.W. *Wirtschafts- und Organisationspsychologie* (pp. 194-219). Weinheim: Beltz.

Scholz, R. W., & Tietje, O., 2002. *Embedded case study methods. Integrating qualitative and quantitative knowledge*. Thousand Oaks: Sage Publications.

Simon, H.A., 1957. *Models of man*. New York: Wiley.

Venix, J.A.M., 1996. Group model building – facilitating team learning using system dynamics. Wiley: West Sussex.

[2] From a theory of science perspective, in many cases a "gentle verification" by agreements of participants seems possible.