Transdisciplinary case studies as a means of sustainability learning

Historical framework and theory

Roland W. Scholz, Daniel J. Lang, Arnim Wiek, Alexander I. Walter and Michael Stauffacher

Department of Environmental Sciences, Institute of Human-Environment Systems, Swiss Federal Institute of Technology, Zurich, Switzerland

Abstract

Purpose – This paper aims at presenting the theoretical concepts of the transdisciplinary case study approach (TCS), which is a research and teaching approach developed and elaborated at the Swiss Federal Institute of Technology (ETH), as a means of transition support.

Design/methodology/approach – The paper reveals the historical roots of case studies, transdisciplinarity and sustainable development as teaching and research paradigms. The TCS approach is presented, which has been developed at ETH for supporting transition management of regional, urban, and organizational systems. This approach is entrenched by an ontology that reveals the basic characteristics of ill-defined transition problems, an epistemology that refers to Probabilistic Functionalism and distinguishes between multi-layered systemic and normative epistemics, a methodology that includes a set of methods for case representation (including modelling and projection), assessment, and strategy building, and a project management model that refers to more than a dozen TCSs in the field of sustainable development. Problems of validity of TCSs as a research methodology are discussed.

Findings – Three major strengths of the TCS approach presented in the paper are: that it is based on three sound paradigms, which focus on different, relevant characteristics of complex, human-environment systems; i.e. the case study approach, transdisciplinarity and sustainable development, that it is strictly organized according to an elaborated and consistent theoretical framework that includes ontological, epistemological, methodological, and organizational considerations, and that it is itself subject to an ongoing inquiry and adaptation process. All theoretical considerations of the paper are clarified be elaborated examples from the more than 10 years experience with TCS of the authors.

Practical implications – The paper gives a comprehensive overview of the theoretical foundation of TCS that might assist other scientists engaged in case study research and teaching to further develop their approaches. Additionally, relevant topics for further research in the field of TCS are presented which hopefully induce an inspiring discussion among case study researchers.

Originality/value – As far we know, this paper is one of the first that presents a comprehensive and theoretically sound overview of applying transdisciplinary case studies as means of sustainability learning. Thus, it can be seen as a first, crucial step for establishing the new research field of TCS

First of all, we want to thank all persons that have been involved in our TCSs (practitioners, students, tutors, experts, scientists, etc.). Without their active cooperation and commitment we would have not been able to develop and establish the approach presented in this paper. Second the authors want to thank the two anonymous reviewers of this paper for their encouraging and supportive comments. Finally we want to thank the editor of the *International Journal for Sustainability in Higher Education* to give us the opportunity to present our approach in this special issue to the readership of this journal.

International Journal of Sustainability in Higher Education
Vol. 7 No. 3, 2006
pp. 226-251

1467-6370
DOI 10.1108/14676370610677829

research and a sound research community of complex, transdisciplinary problem solving towards sustainability learning.

Keywords Case studies, Strategic planning, Sustainable development, Learning

Paper type Case study

1. Introduction

With the turn from the industrial to the post-industrial age, we can recognize fundamental changes of how research (Gibbons *et al.*, 1994; Scholz and Tietje, 2002), teaching (Gutierrez-Martin and Huttenhain, 2003; Mieg, 2000; Zoller and Scholz, 2004), application, and the utilization of scientific knowledge are organized at the university level (Scholz and Marks, 2001; Thompson Klein *et al.*, 2001). Environmental sciences and technology management can be seen as prototypical examples of such a change. Both fields demand for dealing with complex, multi-scale and multi-layered systems, and include knowledge from a broad scope of disciplines. The environmental sciences as its own discipline emerged in Europe from various natural, engineering, and social sciences after a series of environmental disasters in the 1980s. The rationale for this new discipline was that:

> The traditional natural sciences such as chemistry or physics have not been able and prepared to master this type of complex scientific questions concerning environmental systems. Environmental problems constitute a new kind of complex systemic problems that require a new type of methods both for scientific analysis and problem solving (Scholz *et al.*, 1997b, p. 1).

The same holds true for technology development and management (Ashford, 2004). The classical engineer was, for instance, trained in technological problem solving when primarily looking at problems locally or from one dimension. An evaluation of the quality of his product came from inner engineering criteria such as robustness against physical disturbances, at most including aesthetical criteria of appearance. Today, however, we are more aware that connecting two ends via a bridge will have major social, economic, and environmental impacts. Thus, a decision process must also deal with these impacts too. The latter demands on the scientist to not only cooperate with other disciplines but to also work transdisciplinary, as we conceive transdisciplinarity as a process of mutual learning (Scholz *et al.*, 2000) and joint problem solving, in which scientists from different disciplines collaborate with practitioners to solve real-world problems.

If transdisciplinary processes are considered from a societal perspective, the problem solving perspective is in the foreground. From a science perspective, on the contrary, the generation of new knowledge, for instance, about what are appropriate evaluation criteria or what makes a solution socio-technologically robust, is dominating (Flüeler and Scholz, 2004).

This leads us to the relation between transdisciplinarity and case studies. As the fundamental rule "Without methods and methodology, no science!" holds true for the scientific approach of transdisciplinarity, the question arises about what are appropriate transdisciplinarity methods. Case studies have been used for teaching and research in many disciplines for many decades. The case study approach is still viewed with severe scepticism and its potential has been widely misconceived. This is particularly true for the use of case studies as a research methodology.

On the contrary, we will show that case studies, and in particular transdisciplinary case study (TCS), are a powerful tool for teaching and research on complex environmental problems to conduct individual, organizational, and societal sustainability learning. This is particularly due to the fact that TCS goes beyond a qualitative approach and allows for integrating quantitative research methods.

2. History

From a scientific perspective, the TCS approach heavily relies on the case study approach as a means to scientifically treat large-scale, complex problems concerning the interaction of human and environment systems. The case study approach can connect complex real-world problems with scientific theory building, as has been laid out in Eisenhardt (1989). As societal problems are the focus of the TCS approach, it has to take into account the socio-cultural aspects of its research subject. For TCS the principles of sustainable development are an important reference point, as it represents a principle that seems to be widely accepted by most in our society. By using a transdisciplinary procedure we go beyond participatory methods as the stakeholders can and should – at least in some phases of the project – actively contribute to research with their interest and knowledge. This, in turn, has positive effects on questions of implementation. In the following we will briefly touch on these three components of the TCS approach. We will end with the history of the TCS approach itself.

2.1 Case study: research and education

Case study is used in a variety of meanings. In general we can trace different roots such as the medical model (Lukoff *et al.*, 1998), the "case work" of sociology (Le Play, 1855), the role of cases in law sciences (Boehrer and Linsky, 1990), or educational sciences (Kreber, 2001). The boundaries between these roots are sometimes fuzzy. Luria's (1969) famous studies of learning disabilities, e.g. anchored both in medical and in educational sciences and the Piagetian case studies are sometimes labelled as cognitive ethnography, indicating that cultural anthropology (Lévi-Strauss, 1955; Mead, 1923) also contributed to the case study paradigm. As Gomm *et al.* (2000) revealed, case study research has become extremely popular not only in sociology but also in other branches of science, such as policy and public administration research, business sciences, community sociology, management studies, branches of psychology and medicine (particularly neuropsychology), educational sciences, planning sciences, etc.

If we deal with the case study method as a research methodology, the crucial question is for which research objects this approach is appropriate. Normally, the case study approach is mostly chosen in research fields where the historic and authentic dynamics and perspectives of real social or natural systems are considered (Scholz and Tietje, 2002). Or, to express it in other terms, the case study is an appropriate research methodology if the phenomenon investigated cannot be separated from its context. An implicit definition of what is and what makes a case has been provided in Scholz and Tietje (2002):

> A case becomes a case as something specific: it is considered from a specified perspective and with a special interest. A case is unique, one among others (Stake, 1995, p. 2), and always related to something general. Cases are empirical units, theoretical constructs (Ragin, 1992), and subject to evaluation, as scientific and practical interests are tied to them. Cases are utilized for purposes of demonstration and learning, both in education and research.

A closer look reveals that the specific use of case studies in various disciplines is extremely dependent on the type of problems treated and on the nature of the scientific discipline itself. The more complex and contextualized the objects of research, the more valuable the case study approach is regarded to be.

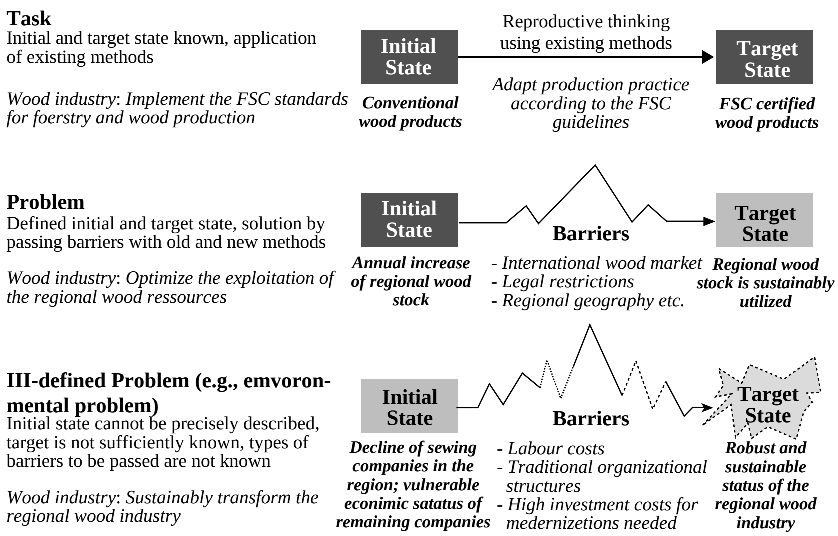
Various classifications and typologies of case study approachs have been introduced (Gomm *et al.*, 2000; Scholz and Tietje, 2002, p. 10; Steiner and Laws, 2006). We think that a case study classification according to the dimensions presented in Table I is, from a research perspective, reasonable and helps to position the TCS approach (for a detailed discussion see Scholz and Tietje, 2002, pp. 9-14). Essential dimensions are the design (i.e. holistic vs embedded, see below), epistemological status (i.e. exploratory vs descriptive vs explanatory), the data (qualitative or quantitative) and the strategy of synthesizing different data (informal, empathic, intuitive vs formative or method driven). Furthermore, cases analyzed have different formats (highly structured presented by short vignettes vs unstructured) and case studies are conducted because of different purposes (research, teaching or action/application). Finally, the motivation of conducting case studies can be intrinsic, if the researcher considers the case as motivated for non-scientific reasons or instrumental if he or she just considers the case as a research tool. The characteristics of the TCS approach with regard to these dimensions are shaded in grey in Figure 1. Explaining all of these characteristics would go beyond the scope of this paper. However, for clarification, we shortly elaborate on two of them which are relevant for the theoretical considerations in this paper.

First, TCSs deal with cases that are unstructured or unstructured for ground breaking (case format). In both case formats, the problem underlying the case and the strategy to cope with this problem are not clearly defined – they represent so-called ill-defined problems (see Section 3.1 on ontology). Cases are classified as unstructured for groundbreaking if researchers suspect that analyzing these cases entails the potential of developing new, groundbreaking scientific theories. These two case formats can be clearly distinguished from short vignettes, which have the character of textbook assignments, and from highly structured cases, which have more degrees of freedom but whose problems and solution strategies are clearly outlined. The latter two case formats are rather used for educational purposes whereas the former are rather research topics (exception described in Stauffacher *et al.*, 2006).

Dimensions	Classification			
Design type	Holistic *Single case*		*Embedded* Multiple case	
Motivation	*Intrinsic*		Instrumental	
Epistemological status	Exploratory	*Descriptive*	Explanatory	
Purpose	*Research*	*Teaching*	*Action/application*	
Data	*Quantitative*		*Qualitative*	
Case format	Short vignettes	Highly structured	*Unstructured*	*Unstructured for ground-breaking*
Synthesis	Informal empathic intuitive		*Formative method driven*	
Science type	Disciplinary	Interdisciplinary	*Transdisciplinary*	

Note: The characteristics of the TCS approach are shown italicized

Table I. A classification of case studies



Notes: TCSs deal with ill-defined problems (III). The examples in italics refer to the TCS "Appenzell Ausserrhoden: Environment, Economy, Region"

Source: Scholz *et al.* (1997b)

Figure 1.
Typology of problems dealing with system transitions

Second, the two main schools of case study researchers are the representatives of a holistic and an embedded type. The term "embedded case study" has been coined by Yin (2003). The embedding of a case is considered as a strategy to master its complexity. In an embedded case study, as in holistic case studies, the starting and ending point is the case as a whole in its real-world context. However, in contrast to holistic case studies, in embedded case studies the case is faceted for the analyses in different perspectives of inquiry or in several subunits, respectively. Moreover, the case is embedded in a defined methodological framework. This process of decomposition and synthesis within a methodological framework are essential aspects of the epistemology of the TCS approach (see Section 3.2 on epistemology).

The case study method has also been extensively used for teaching purposes. It is closely linked to Dewey's (1966) "learning by doing" approach. It takes into account that learning is always context-dependent and culturally influenced. Knowledge is constructed by social interaction with the research object, especially higher-grade procedural knowledge, e.g. complex-problem solving abilities. This is reflected in specific case study methods, such as experiential learning (Kolb, 1984) or experiential case encounter (Scholz and Tietje, 2002). For an intensive discussion please refer to Stauffacher *et al.* (2006) in this issue.

2.2 Sustainable development

The concept of sustainable development defines the normative reference point of the TCS approach. It achieved broader attention by its interpretation in the Brundtland Report "Our Common Future" (World Commission on Environment and Development, 1987), although it can be traced back to a forest management concept in the eighteenth century (von Carlowitz, 1732). According to Dixon and Fallon (1989), the concept had passed through several phases from its biological origin, over a broader resource management concept, to the political implications of the definition in the Brundtland report ("intra- and intergenerational justice"). Within this process the concept has found a broad echo in science (Kates *et al.*, 2001).

Defining the normative reference point of the TCS approach, sustainable development is conceptualized as a dynamic quality of human environment systems (Scholz and Tietje, 2002). Derived from system theoretical approaches (Bossel, 2002), it encompasses three basic principles formulated in potential properties:

(1) maintaining potential of the system (to avoid a collapse);
(2) developmental potential for future generations to satisfy their needs as former ones did (to avoid unbearable restrictions); and
(3) compensatory potential among the subsystems ("corresponding systems").

These interlinked aspects constitute the normative background of the TCSR approach. In a recently published study on expert views of sustainability (Laws *et al.*, 2004), sustainability is revealed as a "problem field that presents both practical and conceptual challenges" which shows that the case study approach is suited for treating sustainable development problems. This is emphasized by the aspect highlighted by Laws *et al.* (2004) that sustainable development is not a fixed concept but requires an ongoing inquiry process.

2.3 Transdisciplinarity

Transdisciplinarity can be said to evolve from special types of problems, i.e. real, complex, socially relevant problems, which ask for the integration of the knowledge of science and society (Burger and Kamber, 2003; Scholz *et al.*, 2000; Thompson Klein *et al.*, 2001). Most of these problems are strongly related to sustainable development (Blättel-Mink and Kastenholz, 2005). It can be said that planning and learning processes for sustainable development require transdisciplinarity as an approach (Meppem and Gill, 1998). This holds particularly true if the development and implementation of policies and mutual learning processes are targeted by the behaviour of individuals, industries, organizations, and governments. We refer to the corresponding process as "sustainability learning".

Transdisciplinarity was mentioned, for one of the first times (Scholz and Marks, 2001), in a 1973 OECD report on environmental education. Transdisciplinarity was defined as a state of knowledge production that occurs, "when a common set of axioms prevail, related to but lying beyond and complementing traditional disciplines" (Emmelin, 1975). Commonly today, transdisciplinarity is understood as a process or an activity that produces, integrates, and manages knowledge in technological, scientific, and social areas (Thompson Klein *et al.*, 2001; Thompson Klein, 2004). As the prefix "trans" indicates, transdisciplinary concerns go beyond disciplines. There are three key components of definition (Häberli and Grossenbacher-Mansuy, 1998; Häberli and Grossenbacher-Mansuy, 2000; Jantsch, 1980; Kötter and Balsiger, 1999; Mittelstrass, 1996; Nicolescu, 1999; Scholz and Marks, 2001) for the TCS approach:

(1) supplementing traditional, disciplinary- and problem-centred "interdisciplinary" scientific activities by organizing processes to incorporate procedures, methodologies, knowledge, and goals from science, industry, and politics;
(2) starting science production from relevant, complex societal problems, thus having the potential to contribute to sustainable development; and

(3) organizing processes of mutual learning between science and society (Scholz and Marks, 2001; Scholz *et al.*, 1998b), so that people from outside academia can participate in transdisciplinary processes.

It can be seen that in the case study approach, sustainable development and transdisciplinarity are strongly interrelated (Adger *et al.*, 2003).

2.4 Transdisciplinary case studies on sustainable development

The Department of Environmental Sciences of the Swiss Federal Institute of Technology, Zurich, was founded in 1987 as a direct response to the environmental disasters of Tschernobyl, Seveso, and Schweizerhalle. From its beginning, research and education was focused on integrated, multi- and interdisciplinary approaches dealing with current, diverse, and complex environmental problems caused by human activities. Thus, the curriculum and research agenda integrate social sciences into the focus of natural environmental sciences. The department aims at contributing to individual, organizational, and societal environmental problem solving abilities (Scholz *et al.*, 1997b).

Against this background, a core element in the spectrum of research and education activities of the department is the annual TCS compulsory for students in their last study year. Between 1993 and 2000, the TCS was annually conducted by the Chair for Natural and Social Science Interface (NSSI) (Scholz *et al.*, 1999; Scholz *et al.*, 1996; Scholz *et al.*, 1997a; Scholz *et al.*, 1998a; Scholz *et al.*, 2001; Scholz *et al.*, 1995). Since, 2000, two case studies are conducted, one from NSSI, the second from another Institute at the Department of Environmental Sciences (Mieg *et al.*, 2001; Scholz *et al.*, 2003, 2004; Scholz *et al.*, 2002).

3. Theory

This paragraph outlines the core elements of the TCS theory to induce and organize sustainability learning. These elements are:

- ontology conceptualizing the phenomenon/problem/case the study is dealing with (against a functional typology of different phenomena/problems/cases);
- epistemology conceptualizing the type of epistemics, i.e. the cognitive approaches, the study is relying on (against a functional typology of different epistemics);
- methodology, conceptualizing the methods the study is applying and their integrative interaction (against a functional typology of different methods); and
- project management theory conceptualizing the project management approach the study is using (against a functional typology of different project management approaches).

These theoretical core elements strongly depend on each other and characterize the basics of transdisciplinary research and teaching in TCSs.

In the following sections, we elementarily outline the core elements and highlight their relevant implications for research and teaching in TCSs. Illustrations and examples are given with reference to a specific TCS. This study was entitled "Appenzell Ausserrhoden: Environment, Economy, Region" and conducted in

2001/2002 in a cooperation between the canton of Appenzell Ausserrhoden, Switzerland and the chair of NSSI at the ETH Zurich. It was a teaching and research project, which dealt with sustainability transitions of traditional business branches (Scholz *et al.*, 2003).

3.1 Ontology

Science always includes reflective components, and we suppose that any researcher wants to know what type of phenomenon/problem/case he or she is dealing with. Ontology attempts to answer this question. It is conceptualized as an inquiry of the basic categories of things and their relations. This inquiry is approached by observational procedures, methods of representation and calculation, rules of logic, etc. Ontological considerations unfold the type, or nature of the phenomenon/problem/case we are dealing with in a TCS.

From the viewpoint of system theory (Clayton and Radcliffe, 1996; Forrester, 1968), a TCS analyses represents:

- the structure of the system (i.e. a city, company, activity, etc.);
- the dynamics of how the system develops and could be developed; and
- the quality aspects of the investigated system with regard to sustainable development.

Problems dealing with transitions of a system can generally be characterized by:

- an initial state of the system;
- a target state of the system; and
- a specific transition process (including certain barriers), which has to be passed for reaching the target state (Figure 1).

The type of problem encountered in TCSs is best classified as an "ill-defined problem" (Scholz *et al.*, 1997b). In this type of problem only the initial state is known and the target state aimed at as well as the transition process in order to reach this target state are, at most, vaguely outlined (Figure 1).

3.1.1 The case of "Appenzell Ausserrhoden: Environment, Economy, Region". An exemplary ill-defined problem within the TCS "Appenzell Ausserrhoden: Environment, Economy, Region" was, for example, the question of how the regional wood, and in particular the sawmill industry, could be sustainably transformed. In this case it was not possible to precisely define the desirable target state (Figure 1) because it was, among other things, unclear how many and what types of sewing companies were beneficial for a sustainable regional development, or if sewing in Appenzell Ausserrhoden contributed to sustainable development at all. At the beginning of the study, it was even unclear how sustainable the current state of the regional sewing industry was. Furthermore, only rough ideas about the transition process and the types of barriers (financial, technical, social, etc.) to be passed during this process existed. This type of problem differs from tasks, such as certifying regional forestry and wood production according to the FSC standards, or defined problems, such as optimizing the exploitation of the regional wood resources (Figure 1).

3.2 Epistemology

Epistemology is the science of generating, integrating, and using knowledge with special focus on structure, scope, biases, validity, etc. as well as cultural, social, and individual differences (Goldman, 1986). It is essential to conduct a study referring to an appropriate epistemological framework in order to adequately segregate and integrate pieces of knowledge acquired. Against the background of a general typology, two spheres of corresponding epistemics are involved in the TCS approach. The two epistemological spheres are the normative and the systemic sphere (Figure 2).

The systemic sphere is embedded in the normative sphere, which means all systemic epistemics are – at least to some extent – selective and value-driven (Hofstetter *et al.*, 2000). Within normative epistemics, we differentiate among fundamental normative structures (e.g. preferences, values) and normative processes of goal formation, assessment, and valuation (e.g. world views). Goal formation results in the guiding question that relies on the normative concept of sustainable development. The guiding question is normatively operationalized in, e.g. assessment criteria. The process of valuation results in, e.g. utility functions for each assessment criterion. The normative processes are based on the fundamental, partly subconscious preference and value structures of the involved agents from science and society. An important goal within the TCS approach is to unfold these values and preferences and make them transparent in order to enable an open discourse among different groups of case agents.

The systemic sphere is hierarchically structured in three epistemics. The structure refers to the criteria of concreteness and complexity (Miller, 1978). The three systemic epistemics are strongly interrelated along the streams of decomposition (down-stream) and synthesis (up-stream) (Figure 3). It is important to note that this structure is to be perceived as "achronic" not "diachronic;" this means that procedural or causal relations between the levels of the hierarchy are not implied. These issues are elaborated in the methodology of the TCS approach (see the following section):

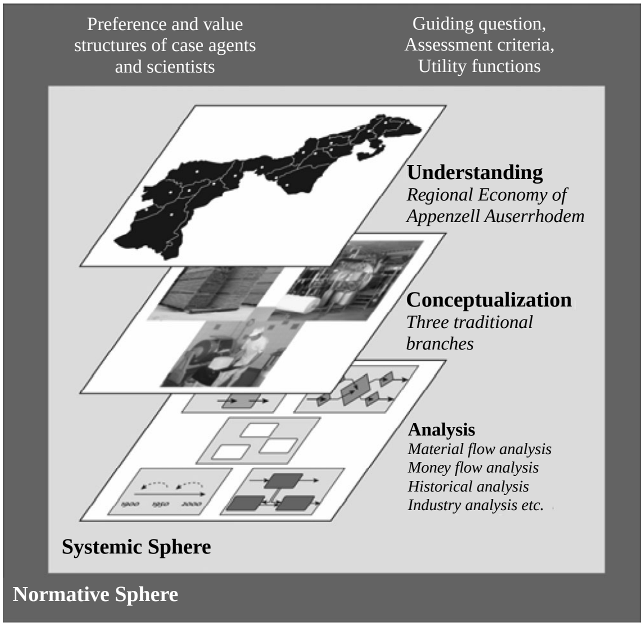
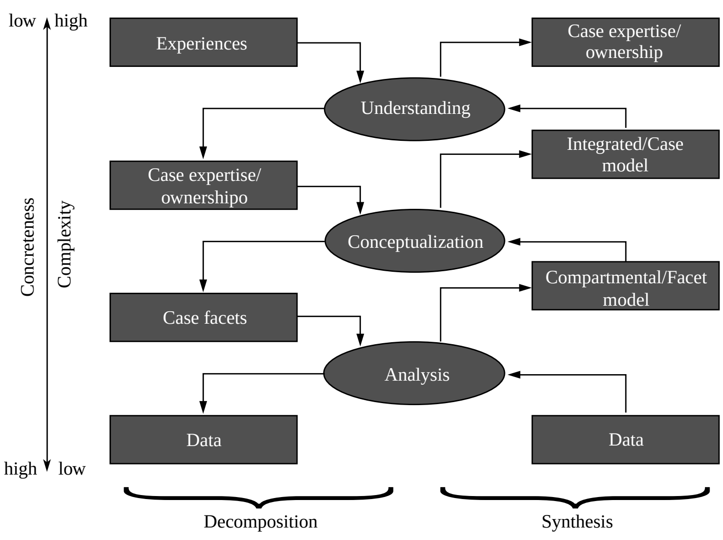


Figure 2.
Epistemological framework of the TCS approach

(1) The top level of the hierarchy is the case understanding (according to Miller, 1978 – "concrete system"). It is characterized by empathy, intuition, and holistic comprehension (Scholz and Tietje, 2002, p. 30 ff.). With respect to the down-stream of decomposition, understanding is mostly based on experiences that result in case expertise and "ownership". Case understanding is the fundamental prerequisite for adequately approaching and dealing with the case. There are special methods that enhance the case understanding, such as the Experiential Case Encounter (Scholz and Tietje, 2002, pp. 241-6). The hierarchical structure implies that the case understanding is the basis for a functional (goal-oriented) conceptualisation and analysis of the case (see levels 2 and 3). Focussing on the up-stream of synthesis, the case understanding is continuously revised and adapted during the study by integrating new data and model elements into the integrated comprehension of the case.

(2) The second level of the hierarchy is the conceptualisation of the case. With respect to the down-stream of decomposition, conceptualisation is based on case expertise and "ownership" and results in facets or subsystems of the case (according to Miller, 1978 – "conceptual system"). The hierarchical structure implies that the case facets build the basis for a functional (goal-oriented) analysis. In terms of the up-stream of synthesis, conceptualization generates an integrated system model, synthesizing subsystems, elements, and interrelations among the elements, which enhances the case understanding. Therefore, methods of knowledge integration are applied to structure and select the relevant system information, i.e. on structures, agents, etc. (Scholz and Tietje, 2002, p. 31).



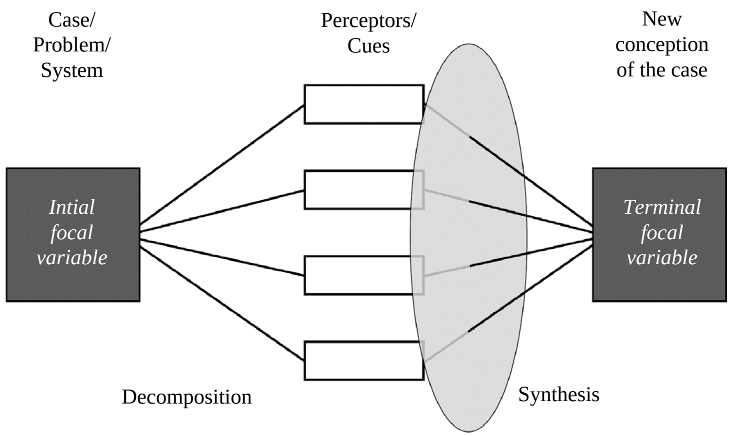
Notes: The graph is not to be read as a diachronological structure that implies a causal or a procedural structure. It is rather to be seen as a basic cognitive and decisional structure. Therefore, the arrows indicate input-output relations rather than sequences. The ellipses denote the levels of epistemics; the boxes information generated by the case study team

Figure 3.
Hierarchy of the systemic sphere of epistemics

(3) The third level of the hierarchy is the analysis of the case facets (according to Miller, 1978 – "abstracted system"). With respect to the down-stream of decomposition, the separated compartments (i.e. the facets) of the case are subject to investigation (Scholz and Tietje, 2002, p. 31). On this level, disciplinary, natural, and social science methods are applied to generate new data (e.g. by observations, measurements, surveys, etc.), as well as to collect existing scientific data (e.g. by content analysis, databases, etc.). In terms of the up-stream of synthesis, the analysed data build the elementary basis for synthesizing and supplementing facet and case models (Figure 3).

The systemic processes are based on fundamental cognitive structures of the involved agents from science and society (i.e. temporal and spatial perceptual structures, categorical structure of reasoning, etc.).

3.2.1 The Probabilistic Functionalism as an epistemological framework. Coping with complex contextualised problems requires an appropriate conceptualisation, and in particular an answer to the question: "How can we manage to accomplish an appropriate/proper/reasonable/acceptable/adequate/… solution for complex, ill-defined problems" that are dealt with in TCSs. Over the last ten years, it turned out that the Probabilistic Functionalism developed by Brunswik (Brunswik, 1950; Hammond and Stewart, 2001) provides very useful framework. Brunswik originally used this concept to explain the performance of complex human perceptual systems. From an epistemological perspective, his basic question in this context was, "how [do] these systems manage to provide a reliable, valid, stable crisp (proximal) image and judgement in the face of such biased, arbitrarily sampled fuzzy (distal) inputs"? As this paper is not the right place to deal with this question in detail (Scholz and Tietje, 2002, pp. 36-9), we only introduce four basic principles of Brunswik's Lens Model, which is the basic representation of the Probabilistic Functionalism (Figure 4). According to Brunswik the following principles have to be considered:



Source: Scholz and Tietje (2002, p.39)

Figure 4.
The Brunswikian Lens Model in its basic shape for TCS

- *Functionality*. Any organismic behaviour (such as the activities of a research team) is intentional or purposeful and functional; thus, defining a terminal focal variable (which comes from the normative sphere, see Figure 2) is essential.
- *Vicarious mediation*. Any organism can only handle a limited number of preceptors (such as measurement stations or facets of a case, see Figure 2). However, these preceptors must be organized in such a way that they can sufficiently represent the initial focal variable (i.e. the case) with respect to the terminal focal variable (i.e. the guiding questions). Because information is gathered probabilistically, and a complete representation of a case is impossible, the perceptors used must be mutually interchangeable for achieving a robust representation or new perception (terminal focal variable). This principle has been called vicarious mediation. With respect to TCS this means that the set(s) of preceptors must be sufficient, i.e. to a certain degree overlapping and as whole, allowing for purposeful description, modelling, and evaluation of the case. Hereby the satisficing rather than optimising principle should be obeyed. This means that a set of preceptors is sufficient if it is "good-enough" (Simon, 1979) with respect to the given questions/problems.
- *Probabilistic relation of information acquisition and integration*. In the context of complex cases, information acquisition always includes probabilistic aspects. With respect to the perceptual systems this means that, "there is no [input] which would be available under all circumstances or is completely trustworthy" (Brunswik, 1955, p. 19). With respect to TCS this analogously means that there exists no ultimate way to approach a case, i.e. the case could never be represented completely objectively. Knowledge on each epistemological level is thus, to a certain degree, acquired in a probabilistic way (e.g. the selected case faceting is one out of many possible faceting approaches). This also holds true for the integration of knowledge.
- *Functional, evolutionary optimisation of performance*. Whether or not a solution to a problem (e.g. recommendations with respect to a sustainable transition of a case) is appropriate/proper/reasonable/acceptable/adequate/... can often only be answered evolutionary. Because reality is not entirely rational, we have to take probabilistic stabilization into account, in the sense that bad solutions can be rewarded whereas good are punished. However, evolutionary, these "misperceptions" get calibrated.

The epistemological framework of Probabilistic Functionalism provides a sound approach, which helps to adequately translate the basic epistemological considerations into a corresponding methodology.

The TCS methodology described in the following chapter is designed along the principles of the Probabilistic Functionalism, repeatedly applying the aspects of decomposition and synthesis. The Brunswikian Lens Model can be considered as a basis for representing the methods applied.

3.2.2 The case of "Appenzell Ausserrhoden: Environment, Economy, Region". The TCS "Appenzell Ausserrhoden: Environment, Economy, Region" focused on the regional economy with respect to the normative guiding idea of sustainable development. At the beginning of the case study a certain case understanding was distributed among the involved case agents and scientists. Sawyers in the region had, for example, a specific understanding of how to treat regional timber best and local majors often knew the key players of the regional economic networks. The goal of the case study team was to make this understanding accessible, in order to adequately organize and accomplish the project and to purposefully contribute, integrate, and enhance this understanding. In so doing, each member of the case study team took part in an Experiential Case Encounter and performed for at least one day a practical exercise as an employee in a traditional occupation of the region (e.g. sawing wood, working as waiter in a regional restaurant, etc.). These encounters were designed as "change of ends" which increased the emphatic understanding of the participants. For conceptualising the case, different approaches following existing "conceptions" were thought of. One idea was, for instance, to facet the case according to the three sub-regions of Appenzell Ausserrhoden; another was to apply the classic economic differentiation between primary, secondary, and tertiary sectors. Finally, the focus on three traditional industrial sectors of the region was commonly considered as the most promising faceting of the case. This conceptualization and the guiding question essentially determined the analytical strategy of the project.

3.3 Methodology

Methodology is conceptualised as a set of principles of methods and procedures developed and elaborated to tackle problems (Checkland, 1999). The TCS methodology strongly refers to the concept of the Probabilistic Functionalism and the related Lens Model (Hammond and Stewart, 2001; Scholz and Tietje, 2002).

The methodological TCS framework is composed of five successive steps ("forward operating"), i.e. goal formation, System analysis, Scenario construction, Multi-criteria assessment, and Generation of orientations (Figure 5) (Schmid and Wiek, 2003; Scholz and Tietje, 2002, p. 268 ff.).

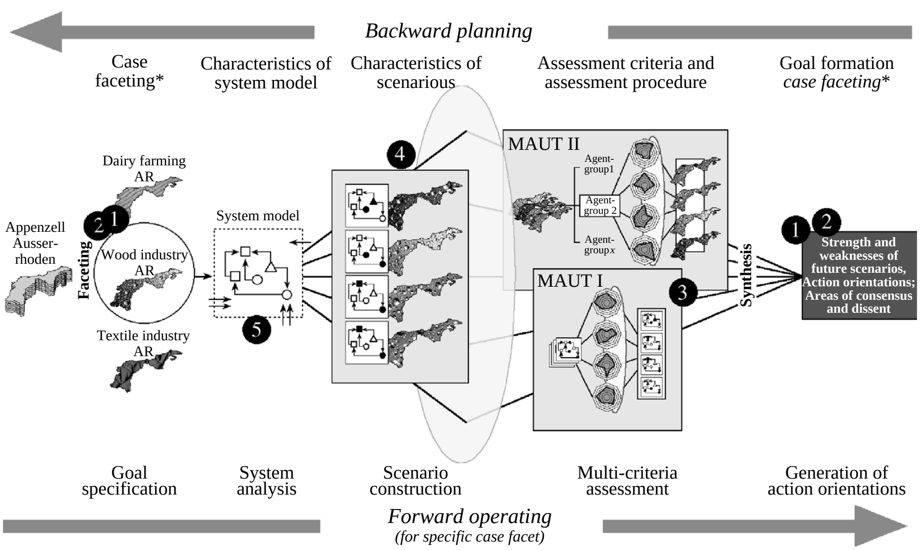


Figure 5.
TCS methodology exemplified for the TCS "Appenzell Ausserrhoden: Environment, Economy, Region"

Notes: *Goal formation and case faceting appear at two points as the facets are defined at the beginning of the "backward planning" process and are the starting point for the "forward operating" during the concrete project work. The synthesis at the end could be subdivided in a synthesis on the level of the case facets and an overall synthesis. For reasons of clarity, we did not include this distinction in the figure

Source: Adapted from Schmid and Wiek (2003)

All steps are conducted with respect to the concept of "backward planning" (Holmberg and Robert, 2000; Scholz and Tietje, 2002, p. 267). This means that they are functionally determined by the goals defined and by the steps they refer to (back and forth). In theory "backward planning" requires that all steps of the project are generally elaborated from "the end to the beginning" before starting with "forward operating". This does not imply that the project team finally fixes the framework of the whole project before starting with the project work. "Backward planning" and "forward operating" are instead performed in an iterative process in which the previously elaborated framework is constantly reflected and adopted on the basis of new insights. "Backward planning" helps, however, to ensure the goal orientation and the functional interplay of the different analytical steps. To implement the concept of "backward planning" it is crucial that the definition of the facets and the formulation of the research plan starts from an integral model (conceptual level) that allows for synthesizing the outcomes of the analyses (analytical level) on each facet in a way that robust conclusions can be derived for the whole case (case understanding). Within the "backward planning" process we rely on the concept of the Probabilistic Functionalism, mentioned above. This methodological functionalism is based on the "satisficing principle," in contrast to achieving completeness (Simon, 1979). Satisfycing means that a method applied should generate results appropriate to build the input for the next step of the procedure, and to contribute to the overall goal of the study (Scholz and Tietje, 2002, p. 38 ff.). Therefore, each method is embedded in a structured set of methods, and its functions are determined by the overall goal, input, expected output, etc. of the case study process (Wiek *et al.*, n.d.). Table II presents the analytical steps of the TCS-framework form the perspective of "backward planning" and "forward operating", respectively.

3.3.1 Goal formation and case faceting. The TCS process starts with the definition of a guiding question. This question should be the result of a contracting process between the key case agents and the team of scientists involved, and be accepted and owned by both parties. The guiding question defines the system and time restrictions, the specific aspects of the sustainability transition aimed for, and the contextual information required for conducting the study.

Backward planning	Forward operating
1. Goal formation (with guiding question)	Goal specification (1, 2)
2. Case faceting (referring to the guiding question)	System analysis (e.g. system model of impact factors) (5)
3. Evaluation/assessment criteria and assessment procedure (who should evaluate what aspects of the facets?)	Scenario/variant construction (e.g. by formative scenario analysis) (4)
4. Characteristics of scenarios/variants (what comparisons with future states can help to answer the guiding question?)	Multi-criteria assessment (e.g. a science/data based and a stakeholder based) (3)
5. Characteristics of system model (what impact factors are most essential?)	Derivation of orientations from the assessments in the facets with respect to the goal of the case study (1, 2)

Note: The numbers refer to Figure 5

Table II. General steps of the "backward planning" and the "forward operating" processes within the TCS approach

The subsequent concept-driven faceting of the case defines the specific subunits, subsystems, compartments, or perspectives that allow best for sufficiently investigating the case with respect to the guiding question. The following aspects should be taken into account when defining the case facets:

- the functional relationship to the guiding question (i.e.: Do the facets cover all essential subunits/perspectives?);
- the feasibility of the study (i.e.: Does the case study team have the financial and personal resources for substantially investigating all facets?); and
- the synthesis and knowledge integration (i.e.: Does the faceting allow for an overall synthesis).

For each case facet the guiding question for related to the entire case has to be specified with respect to the particular characteristics of the facet.

3.3.2 System analysis. The structure, dynamics and functions of each case facet are analyzed by a specific case study project team. This analysis relies on soft system methodology (Checkland, 1999), problem structuring methods (Rosenhead and Mingers, 2001), system dynamics (Forrester, 1971), and other systemic natural and social science methods. The system analysis results in a semi-quantitative system model, which is composed of all impact variables required to sufficiently describe the current and future states of the case and their mutual interactions. This model reveals the relevant regulatory feedback and control mechanisms of the system (Lang *et al.*, 2006; Scholz and Binder, 2004).

3.3.3 Scenario construction. The scenario construction is functionally based on the results of the system analysis and determined by the goal of assessing different possible future states. Within the TCS approach, this step is mainly based on Formative Scenario Analysis (Scholz and Tietje, 2002; further developed in Schmid and Wiek, 2003). This approach is a modular-structured method for intuitively and formatively constructing integrated and consistent scenarios. These scenarios are first mathematically defined, and in a later step verbally formulated, visualized, and validated. Scenarios are conceptualized as complete combinations of levels of all impact variables of the semi-quantitative system model. The elements of the scenario construction (procedure, agents, etc.) are designed in accordance with the function it has to fulfil within the case study, i.e. serving as a basis for the assessment of future states and contributing to the overall goal of the study. Thus, it has to be ensured that the scenario descriptions provide sufficient information for the scenario assessment (backward planning)(Wiek *et al.*, submitted) (Wiek *et al.*, n.d.).

3.3.4 Multi-criteria assessment. The scenario assessment serves for the derivation of action and agent related strategic orientations in the broader methodological TCS framework. It is based on the Multi-Attributive Utility Theory (MAUT) and organized into two separated parts, an expert and a stakeholder assessment. The expert assessment (MAUT 1) aims at assessing the scenarios based on scientific knowledge. The stakeholder assessment (MAUT 2), which aims at unfolding the normative preferences of the relevant stakeholder groups, is organized in a so-called "exploration parcours" (Loukopoulos and Scholz, 2004; Scholz and Tietje, 2002, pp. 143-97 ff.). Within this experimental setting, which provides encounters with the previously developed sample of scenarios (presented by physical models or computer animations), stakeholders are individually asked to assess the scenarios, first intuitively, and then based on a series of sustainability criteria. The procedure involves several steps, including the identification and structuring of relevant criteria to evaluate the scenarios, an assessment of the relative importance of these criteria, the rating of the performance of scenarios with respect to the criteria, and the aggregation of the assessments and the importance weights to obtain an aggregated utility score (Loukopoulos and Scholz, 2004; van Poll, 2003). The fact that MAUT 1 and MAUT 2 are based on the same assessment criteria allows for comparing the expert with the stakeholder assessment, as well as the assessments of the different stakeholder groups. These comparisons unfold different patterns of preferences. The decomposition of the complex issue "sustainable development" in several assessment criteria is beneficial for decision-making processes, because it allows for communicating preference structures and value conflicts among the stakeholder groups and experts.

3.3.5 Generation of orientations. The assessed scenarios, as well as the results and insights of the previous steps (i.e. system analysis and scenario construction), serve as a basis of generating strategic orientations towards a sustainable case transition. It is important to acknowledge that the TCS approach does not aim at a catalogue of action recommendations but at a concise set of action orientations. This fact has to be considered from the beginning of the case study, i.e. the guiding question should incorporate that the TCS aims at constructing scenarios, based on sound system knowledge that differs in terms of sustainability and allows stakeholders and experts to discuss and negotiate desired as well as non-desired future states. In so doing, the TCS approach leaves the decision of how to realise the given orientations to the decision-makers, who know best how to implement the orientations under the given financial, political, and societal constraints (Lele and Norgaard, 1996). Orientations can be made not only on the level of the case facets but also on the level of the entire case. The latter requires a sound overall synthesis of the case study result for which Walter and Wiek (2002) elaborated a formative approach.

3.3.6 The case of "Appenzell Ausserrhoden: Environment, Economy, Region". In an intensive negotiation process between the involved scientists and case agents involved, the guiding question for the TCS "Appenzell Ausserrhoden: Environment, Economy, Region" was defined, as follows: "What are the prerequisites for the regional economy in Appenzell Ausserrhoden in order to sustainably operate in harmony with the environment and the socio-economic needs?" (Scholz and Stauffacher, n.d.). With respect to this thematic focus, three traditional, environmentally relevant, and economically vulnerable business sectors, i.e. textile industry, wood industry, and diary farming, were selected as case facets for the further steps (Scholz *et al.*, 2003). The guiding question was subsequently specifically adapted for each of the facets by the responsible case study project group.

The system analysis included analysing the historical development of the investigated industries, agent networks, production chains, creation of added value, and economic, social, and environmental performance indicators of exemplary companies. Based on the data gathered, relevant system variables were derived and selected with regard to the principles of functional adequacy and sufficiency (Lang *et al.*, n.d.). Finally, these variables and the evaluated data were integrated into a semi-quantitative system model of the specific regional business sector.

Based on the system model, four to six scenarios were constructed for each industry, which described possible future states of the entire sector and its companies. For instance, the five scenarios for the wood industry were:

(1) "business as usual";

(2) "active marketing";

(3) "concentration of all activities to one major company";
(4) "diversification – specialized products"; and
(5) "intensive organizational and logistical corporation of the existing companies".

Because these system scenarios strongly depend on developments of external factors, their robustness under previously constructed shell scenarios was additionally estimated (Wöhrnschimmel *et al.*, 2004).

The described and visualized scenarios were subsequently assessed by experts (MAUT 1) and by representatives of relevant stakeholder groups (MAUT 2). For the facet "wood industry" four stakeholder groups were involved in MAUT 2, with a total of $N = 26$, i.e. sewer, woodworking industry, administration, and forestry/NGOs. The intuitive assessments of the scenarios differed significantly between the stakeholder groups, whereas the groups did not differ significantly in their criteria-based assessments. The results of the criteria-based stakeholder and expert assessments revealed both the same two groups of scenarios that were differently preferred:

(1) the desired scenarios: "active marketing" "diversification – specialized products" and "intensive corporation"; and
(2) the undesired scenarios: "business as usual" and "concentration on one major company".

Based on the insights of the scenario assessment, different action orientations were formulated, which incorporated ideas off all three desired scenarios. One orientation was, for example, that the companies of the wood and forestry industries together might organize and accomplish information events, which would highlight the multiple benefits of wood products and the traditional relevance of the wood industry for the region. This orientation was subsequently implemented by the case agents of the wood industry who have organized an annual public "wood day" (Scholz and Stauffacher, n.d.).

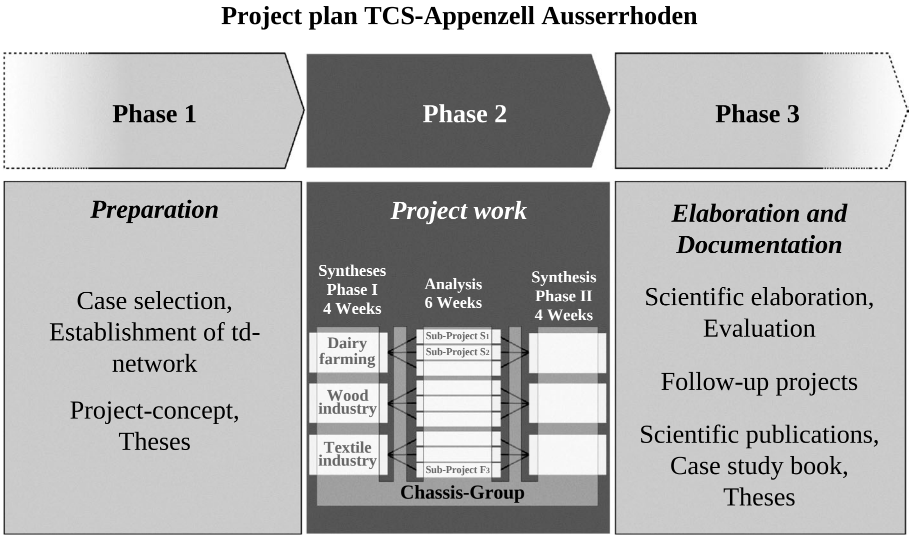
3.4 Project management

Project management deals with the purposeful application of different techniques, tools, and methods for efficiently and effectively utilizing existing skills and knowledge in order to meet the requirements of a certain project (Kerzner, 2003). Hereby, both procedural and organizational aspects play an essential role. The project management framework of the TCS approach accordingly consists of a general procedural project plan (Figure 6) and a general organizational setting (Figure 7). This framework is then specifically adapted for the requirements of each case.

3.4.1 TCS procedure. The procedural project plan is divided into the three major phases:

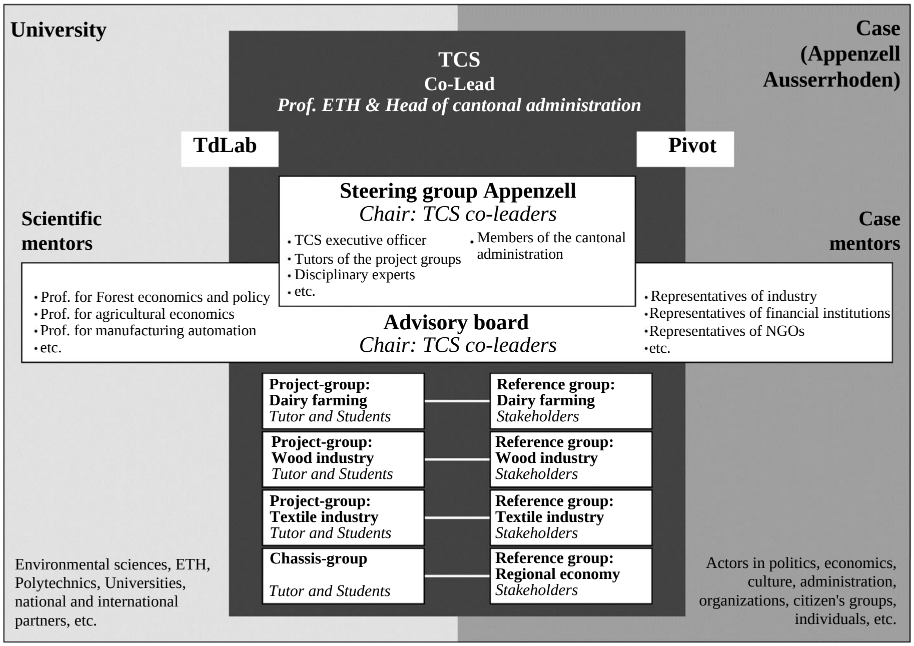
(1) preparation;
(2) project work; and
(3) elaboration and documentation (Scholz *et al.*, 2001) (Figure 6).

During the first phase the general framework for the project is defined herby the concept of backward planning pays an essential role. This phase includes the selection and definition of the case to be analysed (e.g. explicit definition of the system boundaries), the establishment of the transdisciplinary agent network involved in the project (including an explicit definition of roles and competences), and the development of a written project



Source: Scholz *et al.* (2003)

Figure 6.
Procedural project plan of the TCS approach exemplified for the case study "Appenzell Ausserrhoden: Environment, Economy, Region"



Source: Adapted from Scholz *et al.* (2003)

Figure 7.
Organizational chart of the TCS approach exemplified for the case study "Appenzell Ausserrhoden: Environment, Economy, Region"

concept (including the guiding question of the study). The second phase comprises the concrete project work described in the previous methodology chapter. This phase is divided into two synthesis sub-phases and an analytical sub-phase. In the third phase of the project the results of the project work are elaborated and documented. Major results are included in a detailed report dedicated to the case agents and scientific publications dedicated to the scientific community. Depending on the results of the project work, follow-up projects (facilitating the implementation of the results) or thesis (further elaborating the case study results) might be initiated and conducted. Finally, an evaluation of the project and its results, which is essential for the long-term success and further development of the project, is part of this final phase.

3.4.2 TCS organization. To implement the concept of transdisciplinarity, each layer in the general organizational chart of the TCS approach is composed of scientific and case institutions or agents,, respectively, (Mieg, 2000; Scholz *et al.*, 1997b). Following this idea, the project is lead by a co-leadership of a scientist and a case agent, who both have equal rights and responsibilities. The overall administration and organization of the project is either conducted by two interacting project management teams, one responsible for scientific aspects and one responsible for aspects of the case, or by one project management team composed of scientists and case agents. The steering group of the case study, which is strongly involved during the entire project, defines the project framework (guiding question, faceting, etc.) and continuously evaluates the project quality. The project groups conduct the project-work in phase two, which is dedicated to the facets of the case. The groups intensively collaborate with reference groups, composed of representatives of relevant stakeholder groups. Co-leadership, project administration, steering committee, project, and reference groups form the core case study team (centre of Figure 7). This core team is advised and supported by various scientific and case experts. The advisory board, which meets about three to five times during the case study, is an institutionalised form of this support; however, there are many other forms not explicitly visible in the organizational chart, such as a mentoring of the project-groups by disciplinary experts or an external review process of the case study report.

3.4.3 The case of "Appenzell Ausserrhoden: Environment, Economy, Region". The definition of an adequate and feasible guiding question, which similarly meets the requirements of the case agents and those of the involved scientists, was a major challenge during the preparation phase of the TCS "Appenzell Ausserrhoden: Environment, Economy, Region". According to the case agents involved, a relevant problem of the rural region of Appenzell Ausserrhoden has been the decreasing economic power of traditional industrial sectors which have essentially shaped the identity of the region. Thus, they proposed to investigate which role these sectors could and should play for securing the long-term viability of the region. Scientifically, this issue was suited to the question of how human environment systems can be sustainably transformed – a major challenge in sustainability research. Based on this common fundament, which was established in various negotiation meetings, the earlier mentioned guiding question was formulated. The following definition of the case facets was guided by this question, but also influenced by the search for industrial representatives willing to cooperate in the study. Both the definition of the guiding question, as well as the final faceting of the case, exemplify how strongly the TCS approach depends on the knowledge of the agents involved and how practice is incorporated into research (see above). The procedure during phase two is described in the methodology section. During the elaboration and documentation phase various follow-up projects evolved, such as the extrapolation of the results for the regional textile industry for the nationwide textile industry.

The TCS "Appenzell Ausserrhoden: Environment, Economy, Region" was lead by a co-leadership comprised of the two persons who bore the idea of the study – Roland Scholz (ETH-Professor for Environmental Sciences) and Hans Altherr (President of Canton Appenzell Ausserrhoden). This was an ideal constellation for the project, as both co-leaders were strongly committed to the project and had access to highly competent networks within the case and scientific community, respectively. The project management was conducted in a strong corporation between the ETH TdLab, a team of scientists experienced in TCS research and teaching, and a regional office for regional development (pivot), which possessed a comprehensive case understanding. The examples of steering group and advisory board members shown in Figure 7 show that these two organizational bodies were composed of experts from science and practice for both general and specific case aspects. Because the TCS "Appenzell Ausserrhoden: Environment, Economy, Region" was designed as a transdisciplinary teaching project within the ETH-curriculum of environmental sciences, the working groups were composed of advanced students and led by experienced tutors. Members of the corresponding reference groups were, for example, representatives of the investigated industry sectors, related economic agents (e.g. investors), and representatives of the regional administration. With respect to scientific questions, each of the working groups was intensively advised by at least one disciplinary scientific mentor. A special group, the so-called chassis-group, was responsible for integrating the results of the different working groups and for coordinating their activities (Wiek and Walter, n.d.).

3.5 Validity

Validity is clearly the most challenging issue for any research, particularly in qualitative in vivo studies, which are unique in the sense that there is no controlled repetition under the same constraints as postulated in the theory of statistical hypothesis testing. Though essential, the question of validity is often abandoned from qualitative empirical research and has not yet been thoroughly discussed in transdisciplinary research. This paper is not the place to present an in depth discussion of validity in transdisciplinary research, however, we want to introduce some key aspects of validation and sketch out how these aspects could be approached in terms of TCSs. An extensive treatise on the validation of embedded case studies is provided by Scholz and Tietje (2002, p. 331).

Many types and facets of validity have been defined by different sciences. In general terms validity approves the (quantitative or qualitative) correlation between "reality" and the descriptive statements, evaluations, conclusions, recommendations, forecasts, etc. made by researchers or in the case of the TCSs by the case study team. Hereby, validation always refers to a reference framework (Gödel, 1931) or metalevel, which determines what is considered as a true, valid or good and, respectively, as a false, invalid or bad result.

At least the following five aspects seem to be relevant for investigating the validity of TCSs and their results:

(1) First, we can judge whether the study in general or different facets and subprojects are reasonably, effectually, and successfully devoted to the goal or guiding question of the study. This aspect, which has been called functional validity (Elstein *et al.*, 1978; Scholz and Tietje, 2002), strongly refers to the conceptualisation of the case, in particular to the question whether the faceting or embedding seems reasonable to answer the guiding question of the study (Figure 2).
(2) Second, the case study team can inquire whether the appropriate information from the case has been inquired in an unbiased way. This refers to ecological validity, which is a key term in the Theory of Probabilistic Functionalism (see above).
(3) Third, the implications of the study should be in line and not conflict with the goals of the study. This refers to the aspect of consequential validity and can, for example, be object of an ex-post evaluation.
(4) Fourth, from a scientific perspective, some key findings of a TCS should be generic and therefore be also valid for other cases. This refers to the aspect of external validity, for which – to our best knowledge – no standard approval procedure exists.
(5) Fifth, when designing a case study, the research team could plan to investigate key issues by different methods (e.g. interview and questionnaire) or plan to answer the guiding question by a different method (e.g. expert-interview). This is a way of assessing the aspect of convergent validity. This aspect is related to triangulation, which is a key method of validation in qualitative research (Silverman, 2001; Stake, 1995).

The most pragmatic way of validation generally seems to be face validity. In the case of a external validity evaluation, we can, for example, ask different experts to which other cases (e.g. cities, regions, companies, etc.) they think the conclusions of the study could be transferred.

4. Conclusions

Within the fast moving, post-industrialized society, problems become increasingly complex and contextualized. In this paper we argued that an ongoing inquiry process of individual, organizational, and societal sustainability learning is a promising approach to tackle these new challenges and to foster a desirable future.

During our more than 15 years of experience with TCSs, this transdisciplinary project design has proven to be an adequate, flexible, and goal oriented approach to organize and implement sustainability learning processes. Three major strengths of the TCS approach are:

(1) It is based on three sound paradigms, which focus on different, relevant characteristics of complex, human-environment systems; i.e. the case study approach (representing a methodological framework of handling complex, real-world problems), transdisciplinarity (representing a mutual learning framework to cope with the contextualization of complex, real-world problems), and sustainable development (representing a broadly accepted guiding idea that provides a normative orientation for coping with complex real-world problems).

(2) It is strictly organized according to an elaborated and consistent theoretical framework that includes ontological, epistemological, methodological, and organizational considerations. These characteristics are carefully coordinated and interlinked, i.e. the epistemics of the TCS are designed to tackle ill-defined real-world problems, the methodology is organized along the different hierarchical TCS epistemics, and the project organization serves for an effective and efficient application of the methodology. However, the theoretical framework has to be seen as a whole in which ontology, epistemology, methodology, and organization are inseparable "constructs". For instance TCS ontology strongly affects the types of epistemics that are considered relevant for TCS research. Further, the epistemological framework (i.e. the Brunswikian Probabilistic Functionalism) is the reference system for both the methodology and the validation.

(3) It is itself subject to an ongoing inquiry and adaptation process. None of the TCSs we performed was like the other, though the lessons learned from previous studies were continuously integrated into the framework of the subsequent studies.

The paper also revealed that the validity issue has not been sufficiently treated up to now. Though we have introduced a set of aspects/definitions of validity, which are relevant for TCS and also have roughly sketched how validity could be approached in practice, this issue should be more thoroughly investigated in future.

The enthusiasm of most of the more than 1,000 stakeholders involved in the past set of 11 TCSs at ETH, and the starting spread of our approach in different European universities, are very encouraging. However, a crucial next step for the further success of TCS is whether or not a sound research community could be established in the field of complex, transdisciplinary problem solving towards sustainability learning.

References

Adger, W.N., Brown, K., Fairbrass, J., Jordan, A., Paavola, J. and Rosendo, S. *et al.*, (2003), "Governance for sustainability: towards a 'thick' analysis of environmental decision making", *Environment & Planning A*, Vol. 35 No. 6, pp. 1095-110.

Ashford, N.A. (2004), "Major challenges to engineering education for sustainable development: what has to change to make it creative, effective, and acceptable to the established disciplines?", *International Journal of Sustainability in Higher Education*, Vol. 5 No. 3, pp. 239-50.

Blättel-Mink, B. and Kastenholz, H. (2005), "Transdisciplinarity in sustainability research: diffusion conditions of an institutional innovation", *International Journal of Sustainability and World Ecology*, Vol. 12, pp. 1-12.

Boehrer, J. and Linsky, M. (1990), "Teaching with cases: learning to question. In the changing face of college teaching", in Svinicki, M.D. (Ed.), *New Directions for Teaching and Learning Series*,Vol. 42, Jossey-Bass, San Francisco, CA.

Bossel, H. (2002), "Assessing viability and sustainability: a systems-based approach for deriving comprehensive indicator sets", *Conservation Ecology*, Vol. 5 No. 2.

Brunswik, E. (1950), *Perception and the Representative Design of Psychological Experiments*, University of California, Berkeley, CA.

Brunswik, E. (1955), "Representative design and probabilistic theory in a functional psychology", *Psychological Review*, Vol. 62 No. 3, pp. 193-217.

Burger, P. and Kamber, R. (2003), "Cognitive integration in transdisciplinary science: knowledge as a key notion", *Issues in Integrative Studies*, Vol. 21, pp. 43-73.

Checkland, P. (1999), *Soft Systems Methodology: A 30-year Retrospective*, Wiley, Chichester.

Clayton, A. and Radcliffe, N. (1996), *Sustainability – A Systems Approach*, Earthscan, London.

Dewey, J. (1966), *Democracy and Education*, The Free Press, New York, NY.

Dixon, J.A. and Fallon, L.A. (1989), "The concept of sustainability – origins, extensions, and usefulness for policy", *Society & Natural Resources*, Vol. 2 No. 2, pp. 73-84.

Eisenhardt, K.M. (1989), "Building theories from case-study research", *Academy of Management Review*, Vol. 14 No. 4, pp. 532-50.

Elstein, A.S., Shulman, L.S. and Sprafka, S.A. (1978), *Medical Problem Solving*, Harvard University Press, Cambridge, MA.

Emmelin, L. (1975), *Environmental Education at University Level*, Council of Europe, Strasbourg.

Flüeler, T. and Scholz, R.W. (2004), "Socio-technical knowledge for robust decision making in radioactive waste management", *Risk Decision and Policy*, Vol. 9, pp. 129-59.

Forrester, J.W. (1968), *Principles of Systems*, MIT Press, Cambridge, MA.

Forrester, J.W. (1971), *World Dynamics*, Wright-Allen Press, Cambridge, MA.

Gibbons, M.C., Limoges, C., Nowotny, H. and Schwartzmann, S. (1994), *The New Production of Knowledge: The Dynamics of Science and Research in Contemporary Societies*, Sage, London.

Gödel, K. (1931), "Über formal unterscheidbare Sätze der Principia Mathematica und verwandter Systeme I", *Monatshefte für Mathematik und Physik*, Vol. 38, pp. 173-98.

Goldman, A. (1986), *Epistemology and Cognition*, Harvard University Press, Cambridge, MA.

Gomm, R., Hammersley, M. and Foster, P. (2000), *Case Study Method: Key Issues, Key Texts*, Sage, Thousand Oaks, CA.

Gutierrez-Martin, F. and Huttenhain, S.H. (2003), "Environmental education: new paradigms and engineering syllabus", *Journal of Cleaner Production*, Vol. 11 No. 3, pp. 247-51.

Häberli, R. and Grossenbacher-Mansuy, W. (1998), "Transdisziplinarität zwischen Förderung und überforderung", *Erkenntnisse aus dem SPP Umwelt. GAIA*, Vol. 7, pp. 196-213.

Häberli, R. and Grossenbacher-Mansuy, W. (2000), "Transdisciplinarity: joint problem-solving among science, technology and society", paper presented at the International Transdisciplinarity 2000 Conference, Swiss Federal Institute of technology, Zurich.

Hammond, K.R. and Stewart, T.R. (2001), *The Essential Brunswik: Beginnings, Explications, Applications*, Oxford University Press, New York, NY.

Hofstetter, P., Baumgartner, T. and Scholz, R.W. (2000), "Modelling the valuesphere and the ecosphere: integrating the decision makers' perspectives into LCA", *The International Journal of Life Cycle Assessment*, Vol. 5 No. 3, pp. 161-75.

Holmberg, J. and Robert, K.H. (2000), "Backcasting – a framework for strategic planning", *International Journal of Sustainable Development and World Ecology*, Vol. 7 No. 4, pp. 291-308.

Jantsch, E. (1980), *The Self-Organizing Universe: Scientific and Human Implications of the Emerging Paradigm of Evolution*, Pergamon Press, Oxford.

Kates, R.W., Clark, W.C., Corell, R., Hall, J.M., Jaeger, C.C. and Lowe, I. *et al.*, (2001), "Environment and development – sustainability science", *Science*, Vol. 292 No. 5517, pp. 641-2.

Kerzner, H. (2003), *Project Management: A Systems Approach to Planning, Scheduling, and Controlling*, Wiley, London.

Kolb, D.A. (1984), *Experiential Learning Experience as the Source of Learning and Development*, Prentice-Hall, Englewood Cliffs, NJ.

Kötter, R. and Balsiger, P. (1999), "Interdisciplinarity and transdisciplinarity: a constant challenge to the sciences", *Issues in Integrative Studies*, Vol. 17, pp. 87-120.

Kreber, C. (2001), "Learning experientially through case studies? A conceptual analysis", *Teaching in Higher Education*, Vol. 6 No. 2, pp. 217-28.

Lang, D.J., Binder, C.R., Scholz, R.W., Schleiss, K. and Stäubli, B. (2006), "Impact factors and regulatory mechanisms for material flow management: integrating stakeholder and scientific perspectives – the case of bio-waste delivery", *Resources, Conservation and Recycling*, Vol. 47, pp. 101-32.

Lang, D.J., Wiek, A. and Scholz, R.W. (n.d.), "Selecting variables for system analysis applying the principles of functional adequacy and sufficiency", *European Journal of Operational Research*in press.

Laws, D., Scholz, R.W., Shiroyama, H., Susskind, L., Suzuki, T. and Weber, O. (2004), "Expert views on sustainability and technology implementation", *International Journal of Sustainable Development and World Ecology*, Vol. 11 No. 3, pp. 247-61.

Le Play, F. (1855), *Les ouvriers européens*, Imprimerie impériale, Paris.

Lele, S. and Norgaard, R.B. (1996), "Sustainability and the scientist's burden", *Conservation Biology*, Vol. 10 No. 2, pp. 354-65.

Lévi-Strauss, C. (1955), *Tristes Tropiques*, Librairie Plon, Paris.

Loukopoulos, P. and Scholz, R.W. (2004), "Sustainable future urban mobility: using 'area development negotiations' for scenario assessment and participatory strategic planning", *Environment & Planning A*, Vol. 36 No. 12, pp. 2203-26.

Lukoff, D., Edwards, D. and Miller, M. (1998), "The case study as a scientific method for researching alternative therapies", *Alternative Therapies in Health and Medicine*, Vol. 4 No. 2, pp. 44-52.

Luria, A.R. (1969), "On the psychology of computational operations", in Wirzup, J.K.I. (Ed.), *Soviet Studies in the Psychology of Learning and Teaching Mathematics*,Vol. 1, University of Chicago Press, Chicago, IL.

Mead, M. (1923), *Coming of Age in Samoa*, Morrow, New York, NY.

Meppem, T. and Gill, R. (1998), "Planning for sustainability as a learning concept", *Ecological Economics*, Vol. 26, pp. 121-37.

Mieg, H.A. (2000), "University-based projects for local sustainable development: designing expert roles and collective reasoning", *International Journal of Sustainability in Higher Education*, Vol. 1, pp. 67-82.

Mieg, H.A., Hübner, P., Stauffacher, M., Bösch, S. and Balmer, M. (Eds) (2001), *Zukunft Schiene 2 – Ökologisches Potenzial des Schienengüterverkehrs am Beispiel der Region Zugersee*, Rüegger, Zurich.

Miller, J.G. (1978), *Living Systems*, McGraw-Hill, New York, NY.

Mittelstrass, J. (1996), "The modern world and the humanities", *Interdisciplinary Science Reviews*, Vol. 21 No. 4, pp. 284-91.

Nicolescu, B. (1999), "Manifest sur la transdisciplinarité", *Bulletin interactive du CIRET (Centre de Recherche et Etudes Transdisciplinaires)*, Vol. 15, pp. 170-6.

Ragin, C.C. (1992), "Cases of 'What is a case?'", in Ragin, C.C. and Becker, H.S. (Eds), *What is a Case? Exploring the Foundations of Social Inquiry*, Cambridge University Press, Cambridge, MA, pp. 1-18.

Rosenhead, J. and Mingers, J. (2001), *Rational Analysis for a Problematic World Revisited: Problem Structuring Methods for Complexity, Uncertainty and Conflict*, Wiley, Chichester.

Schmid, M. and Wiek, A. (2003), "Abstimmung und Standardisierung von Methoden der komplexen Falltransformation", in Scholz, R.W., Stauffacher, M. and Bösch, S. (Eds), *Appenzell Ausserrhoden: Umwelt, Wirtschaft, Region, ETH-UNS Case Study 2002*, Rüegger und Pabst, Zurich, pp. 229-46.

Scholz, R.W. and Binder, C.R. (2004), "Principles of human-environment systems (HES) research", paper presented at the iEMSs 2004 International Congress 'Complexity and Integrated Resources Management', International Environmental Modelling and Software Society, Zentrum für Umweltkommunikation, Osnabrück.

Scholz, R.W. and Marks, D. (2001), "Learning about transdisciplinarity: where are we? Where have we been? Where should we go?", *Transdisciplinarity: Joint Problem Solving among Science, Technology and Society*, Birkhäuser, Basel.

Scholz, R.W. and Stauffacher, M. (n.d.), "Managing transition in clusters: area development negotiations as a tool for sustaining traditional industries in a Swiss pre-alpine region", *Environment & Planning A*, in press.

Scholz, R.W. and Tietje, O. (2002), *Embedded Case Study Methods, Integrating Quantitative and Qualitative Knowledge*, Sage, Thousand Oaks, CA.

Scholz, R.W., Mieg, H.A. and Oswald, J.E. (2000), "Transdisciplinarity in groundwater management – towards mutual learning of science and society", *Water Air and Soil Pollution*, Vol. 123 Nos 1-4, pp. 477-87.

Scholz, R.W., Mieg, H.A. and Weber, O. (1997b), "Mastering the complexity of environmental problem solving with the case study approach", *Psychology Science*, Vol. 39, pp. 169-86.

Scholz, R.W., Bösch, S., Mieg, H.A. and Stünzi, J. (Eds) (1997a), *Zentrum Zürich Nord: Stadt im Aufbruch, Bausteine für eine nachhaltige Stadtentwicklung*, vdf, Zurich.

Scholz, R.W., Bösch, S., Carlucci, L. and Oswald, J.E. (Eds) (1999), *Nachhaltige Regionalentwicklung: Chancen der Region Klettgau*, Rüegger, Zurich.

Scholz, R.W., Bösch, S., Mieg, H.A. and Stünzi, J. (Eds) (1998a), *Region Klettgau: Verantwortungsvoller Umgang mit Boden*, Rüegger, Zurich.

Scholz, R.W., Bösch, S., Stauffacher, M. and Oswald, J.E. (Eds) (2001), *Zukunft Schiene 1 – Ökoeffizientes Handeln der SBB*, Rüegger, Zurich.

Scholz, R.W., Koller, T., Mieg, H.A. and Schmidlin, C. (Eds) (1995), *Perspektive 'Grosses Moos' – Wege zu einer nachhaltigen Landwirtschaft*, vdf, Zurich.

Scholz, R.W., Mieg, H.A., Weber, O. and Stauffacher, M. (1998b), *Sozio-psychologische Determinanten nachhaltigen Handelns, DISP*, p. 133.

Scholz, R.W., Stauffacher, M., Bösch, S. and Krütli, P. (Eds) (2003), *Appenzell Ausserrhoden: Umwelt – Wirtschaft – Region*, Rüegger und Pabst, Zurich.

Scholz, R.W., Stauffacher, M., Bösch, S. and Krütli, P. (Eds) (2004), *Mobilität und zukunftsfähige Stadtentwicklung: Freizeit in der Stadt Basel*, Rüegger, Zurich.

Scholz, R.W., Stauffacher, M., Bösch, S. and Wiek, A. (Eds) (2002), *Landschaftsnutzung für die Zukunft: der Fall Appenzell Ausserrhoden*, Rüegger, Zurich.

Scholz, R.W., Bösch, S., Koller, T., Mieg, H.A. and Stünzi, J. (Eds) (1996), *Industrieareal Sulzer-Escher Wyss – Umwelt und bauen, Wertschöpfung durch Umnutzung*, vdf, Zurich.

Silverman, D. (2001), *Interpreting Qualitative Data: Methods for Analysing Talk, Text and Interaction*, 2nd ed., Sage, Thousand Oaks, CA.

Simon, H. (1979), *Models of Thought*, Yale University Press, New Haven, CT.

Stake, R.E. (1995), *The Art of Case Study Research*, Sage, Thousand Oaks, CA.

Stauffacher, M., Walter, A.I., Lang, D., Wiek, A. and Scholz, R.W. (2006), "Learning to research environmental problems from a functional socio-cultural constructivism perspective: the transdisciplinary case study approach", *International Journal of Sustainability in Higher Education*, Vol. 7 No. 3.

Steiner, G. and Laws, D. (2006), "From Harvard business school to transdisciplinary case studies", *International Journal of Sustainability in Higher Education*, Vol. 7 No. 3, Bitte Seitenzahlen einfügen.

Thompson Klein, J. (2004), "Prospects for transdisciplinarity", *Futures*, Vol. 36 No. 4, pp. 515-26.

Thompson Klein, J., Grossenbacher-Mansuy, W., Häberli, R., Bill, A., Scholz, R.W. and Welti, M. (2001), *Transdisciplinarity: Joint Problem Solving among Science, Technology, and Society: An Effective Way for Managing Complexity*, Birkhäuser, Basel.

van Poll, R. (2003), "A multi-attributive evaluation of perceived urban environmental quality: an overview", in Hendrickx, L., Jager, W. and Steg, J. (Eds), *Human Decision Making and Environmental Perception*, University of Groningen, Groningen.

von Carlowitz, H.C. (1732), *Sylvicultura oeconomica oder hausswirthliche Nachrichten und naturmässige Anweisungen zur wilden Baum-Zucht*, bey Johann Friedrich Brauns sel, Erben, Leipzig.

Walter, A.I. and Wiek, A. (2002), "Gesamtsynthese der einzelnen Fallstudienergebnisse Siedlung, Freizeit & Tourismus und Natur & Landschaft", in Scholz, R.W., Stauffacher, M., Bösch, S. and Wiek, A. (Eds), *Landschaftsnutzung für die Zukunft: der Fall Appenzell Ausserrhoden. ETH-UNS Case Study 2001*, Rüegger und Pabst, Zurich, pp. 203-49.

Walter, A.I. and Wiek, A. (n.d.), "A formalized transdisciplinary approach to integrate sectoral planning and decision-making in complex systems", *European Journal of Operational Research*.

Wiek, A., Binder, C.R. and Scholz, R.W. (n.d.), "Functions of scenarios in transition processes", *Futures*, in press.

Wöhrnschimmel, H., Logue, J. and Lang, D.J. (2004), "Holzwirtschaft im Appenzellerland [Timber Industry in the Region Appenzell]", in Scholz, R.W., Stauffacher, M., Bösch, S. and Krütli, P. (Eds), *ETH-UNS Fallstudie 2002: Appenzell Ausserrhoden – Umwelt, Wirtschaft, Region [ETH-UNS Case Study 2002: Appenzell Ausserrhoden – Environment, Economics, Region]*, Verlag Rüegger in cooperation with Pabst Science Publishers, Zurich, pp. 105-62.

World Commission on Environment and Development (1987), *Our Common Future (The Brundtland Report)*, Oxford University Press, Oxford.

Yin, R. (2003), *Case Study Research: Design and Methods*, Sage, Newbury Park, CA.

Zoller, U. and Scholz, R.W. (2004), "The HOCS paradigm shift from disciplinary knowledge (LOCS) – to interdisciplinary evaluative, system thinking (HOCS): what should it take in science-technology-environment-society oriented courses, curricula and assessment?", *Water Science and Technology*, Vol. 49 No. 8, pp. 27-36.

Corresponding author
Roland W. Scholz can be contacted at: roland.scholz @env.ethz.ch