

Structuring complexity for tailoring research contributions to sustainable development: a framework

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Abstract Research aiming at generating effective contributions to sustainable development faces particular complexity related challenges. This article proposes an analytical framework disentangling and structuring complexity issues with which research for sustainable development is confronted. Based on theoretical conceptions from fields like policy sciences and transdisciplinary research as well as on an in-depth analysis of the concept of sustainable development, three meta-perspectives on research for sustainable development are introduced and elaborated. The first perspective focuses on notions of sustainable development, sorting out the problem of unclear or ambiguous interpretations of the general sustainability objectives in specific contexts. The second perspective introduces a broad conception of the policy process representing the way societal change towards sustainable development is brought about. It supports identifying those academic and non-academic actors and stakeholders that are relevant for coming up with effective knowledge contributions. The third perspective identifies

different forms of knowledge that are needed to tackle sustainability problems as well as the significance of their mutual interrelations. How the framework perspectives support reflecting on the fundamental complexity issues research for sustainable development is confronted with is illustrated using a case example from natural scientific research in the field of land use. We argue that meeting the complexity inherent in the concept of sustainable development requires joint learning in policy processes, working out shared visions being in line with the core objectives of sustainable development and generating knowledge about empirical, normative and pragmatic aspects.

Keywords Complexity · Sustainable development · Sustainability research · Policy-oriented research · Science-policy nexus · Policy cultures · Knowledge forms · Science studies

Introduction

Research that is responsive to society's concern about sustainable development, as asked for by the Agenda 21 (UN 1993, Chap. 35), is considerably challenged by the complexity of this task. Furthermore, the heterogeneous factors that make up this complexity as well as their interplay are only partly understood. For example, the meaning of the term sustainable development often appears to be unclear, and accordingly largely underdetermined, ambiguous and controversial (Parris and Kates 2003; Robinson 2004; Williams and Millington 2004; Fergus and Rowney 2005; Kates et al. 2005). Identifying adequate strategies and measures to induce the required changes is not trivial either: often, "there are marked differences of opinion over the way in which sustainable development

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might be achieved” (Redclift 1992, p. 395). Such questions are complicated by the fact that processes of societal change happen constantly and often simultaneously on a variety of different but interwoven spatiotemporal scales and societal levels, in different private and public sectors, involving different actors ranging from individuals to local, national or transnational NGOs, business companies and governmental bodies as well as their respective networks.

Contributions of research to sustainable development can range from (1) insights on functional structures, causal relations and normative principles for assessing whether current practices are sustainable, to (2) suggestions for more sustainable ones, as well as to (3) the identification of barriers and opportunities for adopting them. In view of the broadness—in terms of the heterogeneity of the correspondingly relevant factors—and the complexity of this task, research runs the risk of inadequately simplifying sustainability problems. Researchers might misconstrue or overlook the context (Clark 2002) and produce results that are not relevant, not used or lead to unsustainable outcomes (Funtowicz et al. 1998, p. 4). And “even where research is potentially relevant, research results may not provide the specific information needed to support policy, may be provided too late, may not be understood, may not be valued, or the information provided may conflict fatally with preconceptions, vested interests, or current policy” (Pannell and Roberts 2009). If research in contrast tries to fully embrace the complexity of sustainability issues, it easily overburdens itself (Pohl and Hirsch Hadorn 2007, p. 39). Thus, the way researchers frame and investigate sustainability challenges is crucial for whether and how their efforts will really affect sustainable development. A core difficulty is to engage effectively with the related complexity.

This article proposes a conceptual framework that disentangles and structures the core complexity issues with which research for sustainable development is confronted. “Research for sustainable development” is thereby used for research that is directed at supporting sustainable development by providing knowledge about whether change is needed, and if so, how it can be brought about. Thus, the article addresses basic, applied or transdisciplinary research that explicitly aims at contributing to sustainable development (Fig. 1). The framework supports scientists in ‘tailoring’ their research to sustainable development, i.e., in enhancing the effectiveness of their research through systematically reflecting on complexity issues when designing or evaluating the respective contributions. Thus, the framework specifies requirements for research approaches; it is not a specific research approach like for instance an integrated theory. How the relevant issues can effectively be considered in a specific study needs to be determined on a project basis, as will be

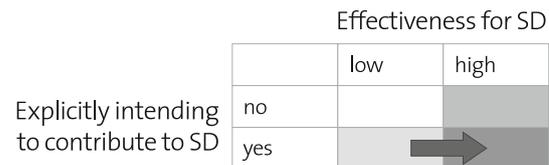


Fig. 1 The framework proposed in this article aims at increasing the effectiveness of research that is directed at contributing to sustainable development

illustrated below. The framework has been developed with a focus on natural sciences’ contributions to sustainable development. However, many underlying considerations may go beyond the respective disciplines as well as beyond academia. Thus, the framework may also support actors and stakeholders from institutions in the public and private sector as well as the civil society in reflecting on their expectations as research addressees, as well as on their own inputs to policy processes. Elaborating this here would transgress the scope of this article, however. Similarly, we focus on cognitive complexity in this article and cannot cover the equally demanding institutional challenges that research for sustainability faces. How to deal with diverse institutional backgrounds is a crucial challenge in setting up projects, getting them funded, conducting research and bringing results to fruition. However, understanding cognitive complexity is also a prerequisite for addressing institutional complexity.

The mission of research for sustainable development entails three key elements, representing at the same time key sources of complexity. The first key element refers to the meaning of the term sustainable development. Scientific studies feature an underlying notion of sustainable development, i.e., an idea about what kind of development researchers think should be striven for in the context of their investigations. Such notions inform the problem definition and can be decisive for the usefulness of the research. The second key element arises out of the question of how to achieve sustainable development. What could be effective strategies and measures is typically discussed and decided in some sort of policy processes in the broadest sense. Thus, research for sustainable development refers to such processes, and correspondingly to certain states of discussion, time frames, scales, levels as well as actors and stakeholders. The role of researchers should not be underestimated in this regard, as policy making can be considerably influenced by scientific understanding of real world problems (Jerneck et al. 2010). The third key element deals with the nature of knowledge required for promoting sustainable development. The typical concept of (natural) scientific knowledge does not usually explicitly also account for normative and pragmatic aspects like, for example, specific development goals or technological

options. Supporting sustainable development therefore requires distinguishing knowledge of different forms, relating and if necessary adapting them to each other. This may involve various scientific cultures as well as further experts, which additionally increase complexity.

The conceptual framework presented in this article takes up the complexity-related key elements that are inherent in research for sustainable development (Fig. 2). Conceptualized as three analytical perspectives on scientific knowledge contributions, these three core sources of complexity build the basic framework elements. We refer to them as the sustainability objectives, the policy processes and the knowledge needed for this purpose.

The framework is based on reflective analyses from a philosophical and science studies perspective, and on theoretical conceptions from fields like policy sciences and transdisciplinary research. In addition, it integrates an in-depth analysis of the concept of sustainable development as presented by the Brundtland Commission (WCED 1987). It is inspired by work on the societal relevance of research in general like the identification of value judgments and the importance of knowledge integration and stakeholder participation (Noelting et al. 2004), broadly applicable principles for designing transdisciplinary research (Pohl and Hirsch Hadorn 2007) and general sets of questions that typically need to be tackled for societal problem solving (e.g., Lasswell 1971; Brewer 2007).

In the following, the three framework perspectives are elaborated. First, the concept of sustainable development is analyzed with respect to its complex nature and meaning, and the consequences for research are clarified. Second, the model of the policy cycle and the concept of policy cultures are introduced as a means to structure the complexity of policy processes. The third section distinguishes three forms of knowledge that are needed to tackle sustainability problems and clarifies how to relate and adapt them to each other in research. In the fourth section, we summarize the

basic features of the framework and illustrate them using a case study from natural scientific research in the field of land use. We conclude by pointing at the significance of the framework for doing effective research for sustainable development.

The sustainability objectives

According to the World Commission on Environment and Development (WCED),

Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts: the concept of ‘needs’, in particular the essential needs of the world’s poor, to which overriding priority should be given; and the idea of limitations imposed by the state of technology and social organization on the environment’s ability to meet present and future needs (WCED 1987, p. 43).

This definition has been extremely influential (Mitchem 1995, p. 316) and is still the one most broadly approved and referred to today (Kates et al. 2005; Sneddon et al. 2006), both within and outside the academic community. The WCED’s message is that we should strive for satisfying our needs by complying with certain basic conditions that frame our individual or collective activities. However, the contents of these basic conditions or objectives seem to have been, to some extent, forgotten (Redclift 1992, p. 19) or seem to be unclear (Parris and Kates 2003; Robinson 2004; Williams and Millington 2004; Fergus and Rowney 2005; Kates et al. 2005). In order to clarify them, the contents of the concept of sustainability as introduced by the WCED is, in the following, interpreted and specified with respect to fundamental issues they raise.

Intergenerational equity

The first basic or core objective stated in the definition refers to the ability of future generations to meet their needs. The Brundtland report raises the concern of inequality between present and future generations typically referred to as intergenerational equity. It deals with the “natural and cultural heritage that we will pass on to future generations” (Brown Weiss 1989), encompassing positively connoted cultural and technological achievements, as well as negative legacies like degraded resources, pollution and negative impacts of climate change. The obligations of the present to the future generations are based on moral rights assigned to the latter (Meyer 2008). With regard to the ability of meeting needs, the claim for fairness

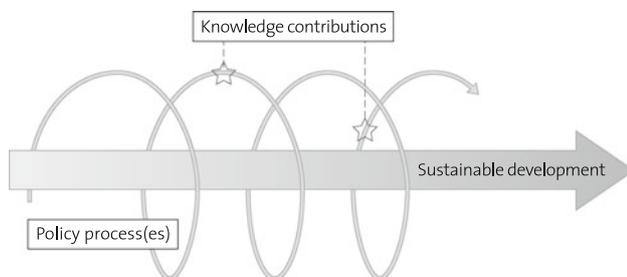


Fig. 2 Three main sources of complexity in research for sustainable development: (1) the implicit or unclear objectives of policy processes directed at sustainable development; (2) the interplay of a multitude of actors and stakeholders in policy processes, pushing or hindering change; (3) the interwoven empirical, normative and pragmatic aspects of sustainability challenges for which scientific knowledge contributions have to account

in allocating resources is a first major issue (Jabareen 2008), but also more generally the distribution of costs and benefits of the respective activities. Thus, for the present generation, intergenerational equity means to account, with its activities, for the future generations' requirements to meet their needs while minimising negative impacts on their livelihoods. However, we need to make respective assumptions as to these requirements, especially in terms of resources, technologies, capital and freedom of scope.

Intra-generational equity

The second core objective of sustainability asks of the present generation to give overriding priority to the essential needs of the world's poor when satisfying its own needs (WCED 1987, p. 43). This refers to the problems of inequality and poverty within the present generation, i.e., to intra-generational equity. Intra-generational equity requires that all people have living conditions that allow them to live a humane life. The conception of basic or essential needs represents the minimal level of well-being, encompassing survival (sustenance, basic health, energy, housing, water supply and sanitation) and employment (WCED 1987, p. 54). Beyond that, a sustained increase in the level of collective and individual welfare is advocated (WCED 1987, p. 8; Dixon and Fallon 1989). Similar to the conception of intergenerational equity, the main goal here is a fair distribution of the access to the constrained natural resource base and, more generally, a fair distribution of costs and benefits of development (WCED 1987, p. 43). Examples are the health costs of diseases due to irreversibly polluted rivers and soils or the benefits of economic returns in the form of income. The prerequisite for addressing intra-generational equity is a fair distribution of economic and political power (WCED 1987, p. 46; Boyce 1994) such as participation in decision-making and democratic processes (WCED 1987, p. 63). For enabling participation, suitable forms of governance need to be established.

Environmental integrity

We refer to the third core idea as to environmental integrity. It encompasses the sustainment of the natural resources being our direct livelihood and important basis for economic development as well as the "ability of the biosphere to absorb the effects of human activities" (WCED 1987, p. 8). Environmental integrity requires finding a balance between the use and transformation of environmental systems and their protection and restoration. Thus, it must be decided which natural resources or life-supporting systems should be used, transformed, protected or restored, how and to what extent. For renewable resources, a "maximum sustainable yield taking into

account system-wide effects of exploitation" (WCED 1987, p. 45) should be determined, whereas for non-renewable or stock resources, parameters like thresholds, availability of substitutes and recycling should be taken into consideration (WCED 1987, p. 46). Similarly, it must be decided which substances can be released back to the environment, how and to what extent.

Complexity challenges for research

These three core objectives are the substantive normative requirements for sustainable development following the conception of the Brundtland Commission. Most importantly, they are strongly interlinked and thus must not be considered separately: increasing poverty and global inequality are not only major development trends that need to be changed, but also obstacles in fighting environmental degradation (WCED 1987, p. 3/4). The integration of inequality and environmental concerns was accordingly a main achievement of the Brundtland report (e.g., Mitcham 1995, p. 317; Lafferty and Langhelle 1999, p. 2). Equitably using natural resources by present and future generations depends on sustaining environmental integrity. Intra- and intergenerational equity in meeting needs refers to principles on fair resources allocation, while environmental integrity is about criteria limiting the use of natural resources to sustain the quality of important ecosystems. This illustrates that although closely related these are different normative requirements. In short, we argue that we need to reflect on our activities' effects as to all three core objectives of sustainability specified above, paying particular attention to their mutual interdependencies.

Note that although the widely used three-pillar model of sustainability also responds to the multidimensional nature of the concept, its general normative requirements—economic development, social development and environmental protection—are different from the Brundtland definition. The Brundtland definition puts economic development, which basically means progress in the way we meet our needs, at the core and formulates respective sustainability conditions for the related activities. Economic development therefore has a completely different role in the concept of sustainable development than the three-pillar model implies. We therefore advocate relating sustainability indicators to the above-identified core objectives being normative requirements as to the way we meet our needs.

On a general level, the Brundtland conception of sustainability is broadly approved but has been interpreted in varying ways, depending on the perspective (Lélé 1991; Parkin 2000; Robinson 2004; Fergus and Rowney 2005; Grunwald and Kopfmüller 2006). This flexibility in interpretation can be explained by conceiving sustainable development as a contestable political concept like, for,

e.g., ‘democracy’ or ‘fairness’ (Jacobs 1999). Due to its nature this kind of concept has no precise unitary meaning (Gallie 1956). Jacobs accordingly distinguishes a first, “unitary but vague” level of meaning, allowing for a short definition with a “number of ‘core ideas,’” from a second more precise level with plural and contested meanings, characterized by “political argument over how the concept should be interpreted in practice” (1999, p. 25). The fact that in most specific contexts sustainable development can have various equally legitimate forms and specifications easily leads to diverse and ambiguous interpretations. Thus, there is a need for deliberating concrete goals and working out shared pictures of what sustainable development in the context of specific real world problems should look like. The principle of participation advocated by the Brundtland report (WCED 1987, p. 63) calls for doing this comprehensively, i.e., promoting the common good rather than attaching greater significance to particular interests and veering away from the original goals (Fergus and Rowney 2005). Therefore, such debates need to stick to the general objectives of sustainable development when investigating a specific real world problem in a given context and determining the concrete goals and means for a sustainable development for this problem.

Distinguishing the general level of meaning of sustainable development—the three core objectives—from the level of specific understandings allows accounting for the nature of this normative concept in research and correspondingly building on adequate sustainability conceptions in the context of the problem situation referred to. Especially specific understandings of those having a stake in this problem should not be forgotten. Adequate sustainability conceptions in research take up the relevant specific understandings and make sure they are in line with the general core objectives of sustainable development.

Research supporting policy processes

In societal contexts, development means “social change over time” (Lafferty and Langhelle 1999, p. 2). The Brundtland Commission adopted a comprehensive notion of development as “a progressive transformation of economy and society” (WCED 1987, p. 43), involving policy processes in different private and public sectors as well as on different societal levels and spatiotemporal scales to bring about changes in the prioritization and understanding of needs and the way they are met. This allows for top-down governance efforts as asked for by the WCED (1987) as well as for bottom-up initiatives like, for example, self-organization by resource users (Ostrom 2009).

The term policy in a broad sense is a principle or guideline for action (Clark 2002, p. 6) or “a plan of action,

statement of ideals, etc., proposed or adopted by a government, political party, business, etc.” (Hornby 1995, p. 893). In this article, we refer to the process of formulating and implementing a policy as policy processes, ranging from planning and determining actions to reflecting, adapting or stopping them.¹

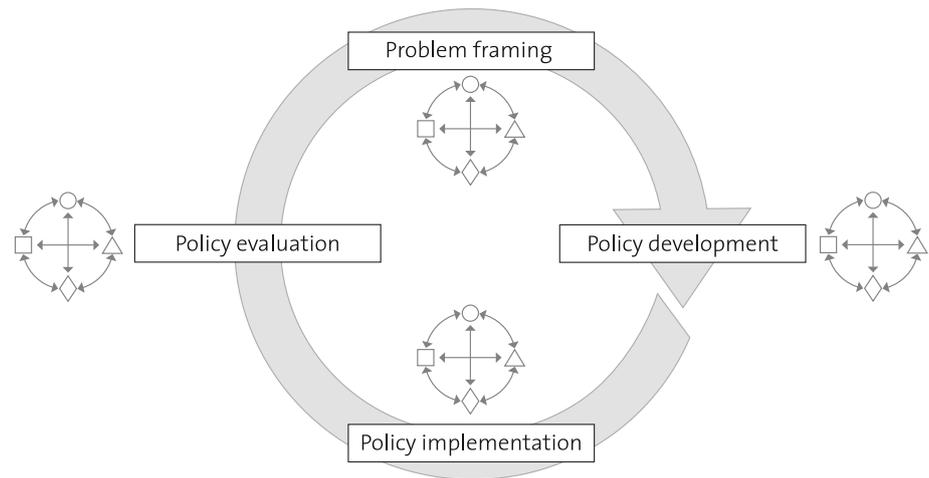
Research that is committed to supporting sustainable development has to be concerned with understanding current and exploring alternative sorts, contents and aims of policies and policy processes as well as their implications on humans and nature. This understanding may comprise studies of desired goals and their advocates, actual trends and their drivers, factors that are responsible for the trends, implications for the future as well as possible course correcting measures (Lasswell 1971; Brewer 2007). By adequately considering opinions about what could be appropriate policies, as well as the ways policies evolve and are applied at specific scales and in particular time frames, research can increase its policy relevance.

The stages approach to the policy process

A model that structures policy processes is the so-called stages approach. Lasswell originally proposed it as a heuristic device “to help disaggregate an otherwise seamless web of public policy transactions” (deLeon 1999, p. 24). The model splits the process of formulating and implementing a specific policy into a number of stages. The four most general stages in the policy process are (1) problem framing, (2) policy development, (3) policy implementation and (4) policy evaluation (Quevauviller et al. 2005). Some authors further elaborate and sub-divide the four stages and come up with six (Brewer 1974; Norse and Tschirley 2000), seven (Lasswell 1972) or eight (Bridgman and Davis 2003) stages. Problem framing is about the understanding and structuring of the problem to be addressed in the policy process. In the case of sustainable development, problem framing includes both determining reasons for unsustainable practices as well as working out the respective specific goals. Policy development means proposing principles or guidelines for acting on the problem such as, for instance, defining critical limits for the use of certain natural resources. Policy implementation includes operationalizing of principles and deciding on measures. Policy evaluation is about the monitoring and assessment of the effects of policy implementation. The stages approach to policy processes

¹ Note the similarity to the concept of governance, which stresses that “economic and social policy is no longer the exclusive preserve of governments. Human rights advocates, gender activists, developmentalists and groups of indigenous peoples have invaded the territory of states, literally and figuratively” (Weiss 2000). As distinguished from the notion of governance, the conception we apply has a stronger focus on the content and direction of development, however.

Fig. 3 Simple four-stage approach to the policy process. A policy process and its outcome is the result of the continuous interplay of different policy cultures: the public sector (*triangle*), the private sector (*diamond*), civil society (*circle*) and academia (*square*)



ends with a policy cycle by re-entering stage (1) after passing stage (4) (Fig. 3).

Note that the stages approach to policy processes describes an idealized model. In real world policy-making the stages can overlap, take place simultaneously, follow a different order or require iterations (Hueston 2003; Howard 2005). Furthermore, policy processes in the real world are influenced by a diversity of factors like power relations, current policies or historical circumstances (deLeon 1999; Sabatier 1999; Jann and Wegrich 2007, p. 44). The stages approach serves as a “basis for viewing and categorizing actors and actions in a way that helps unravel and elucidate given policies, both in retrospect (always, of course, the clearer view) and—more cautiously—in the future” (deLeon 1999, p. 26). It is a heuristic tool to structure a messy real world process as if it would be a planned and rational one. It does not, however, fully describe most real-world policy making “where time is limited, issues are politically charged and governments are reluctant to reveal their own values and priorities” (Howard 2005, p. 10).

For the purpose of the framework we use the four-stages model of the policy process. This model helps disentangle various interwoven kinds of processes, namely processes of identifying sustainability challenges, of developing principles and guidelines to address them, of determining measures for implementation as well as of coming up with means for evaluating their effects.

The concept of policy cultures

Following Elzinga, Jamison and others we distinguish four main groups or policy cultures that are involved in policy processes and their outcomes: (1) the public sector, (2) the private sector, (3) civil society and (4) academia (Elzinga and Jamison 1995; Elzinga 1996; Jasanoff and Wynne 1998). Note that these groups are not generic but rather a rough structuring of the diversity of potentially relevant

actors and actor groups using the example of current western democratic societies. Analogous to a governance process, a policy process is “a result of the interaction of many actors who have their own particular problems, define goals and follow strategies to achieve them.” (Voss and Kemp 2006, p. 9) (Fig. 3). The interplay of the policy cultures in the policy process implies “that scientific inputs constantly feed the environmental policy process” (Quevauviller et al. 2005, pp. 204–204), and not for example merely the stage of problem framing. Vice versa, input from other policy cultures can constantly feed into research through exchange or participation.

In current research for sustainable development the non-academic policy cultures are often conceived as stakeholders (Gass et al. 1997; Koontz and Moore Johnson 2004; Berghöfer and Berghöfer 2006; Hindenlang et al. 2008; Hisschemöller et al. 2009; Hage et al. 2010). The concept of stakeholders was originally developed in the private sector and related to firms (Lawrence and Cook 1982, p. 329). Therefore, in management literature stakeholders are usually characterized by their interest and power through which they can influence a firm’s business and growth (Mitchell et al. 1997). This historical rooting of the concept in the private sector may be the reason why stakeholders are characterized mainly by power and interest in the context of sustainable development as well (Start and Hovland 2004; Mushove and Vogel 2005; Reed et al. 2009). However, the non-academic policy cultures additionally possess specific expertise needed for developing a comprehensive understanding of the current situation, including its perception and appraisal, its dynamic and its change towards sustainable development (Wynne 1991; Bagamoyo College of Arts et al. 2002; Hubert et al. 2008; Thompson and Scoones 2009).

In research for sustainable development the academic policy culture is usually characterized in terms of expertise only. Seen as policy culture, however, researchers

furthermore hold power and specific interests. To emphasize power and interests of researchers Gass et al. (1997, p. 122) define stakeholders including “ourselves (social science researchers with our own perceptions), along with other disciplinary categories such as policy makers, engineers, technical researchers and extension officers, as subjects of an analysis in which there are strictly no objective or disinterested parties.” The influence of the IPCC on European and US-American climate policy-making and the concurrent growth of climate research is a recent example of the academic sector’s power and interest as well as of how the agendas of both policy cultures relate to each other. Hence, all four policy cultures involved in considering and, if need be, bringing forward change towards sustainable development have interests, power and expertise.

Interest

Interest is what the policy cultures are striving for. Roughly spoken, the specific interests of the four policy cultures are as follows (Elzinga and Jamison 1995; Elzinga 1996; Pohl 2008): (1) the academic sector’s interest is to produce knowledge and to get further funding for research; (2) the private sector is interested in developing and selling products at a profit; (3) the public sector is interested in regulating and governing the other sectors; (4) civil society is interested in participating in decision-making. The Brundtland Commission contrasts these interests with the common good (WCED 1987, p. 46; Hirsch Hadorn and Brun 2007). Hence, policy cultures involved in research for sustainable development are requested to bring their particular interests in line with promoting the common good.

Power

By power we mean the possibility to impose one’s will onto others even if they disagree and oppose (Weber 1962, p. 117). In policy processes a policy culture wields power when not consulting others, when consulting others but dismissing what they say or when discrediting a policy culture’s expertise. The exchange with other policy cultures—their participation—does imply power relations. Arnstein’s (1969) ladder of citizen participation, for instance, counts five rungs of wielding power (manipulation, therapy, informing, consultation, placation) before coming to three rungs of shared power (partnership, delegated power, citizen control). A policy culture or a powerful representative exercises power, for example, by imposing a specific view of the problem, solution to the problem or idea of sustainable development to other representatives or policy cultures. Furthermore a non-sustainable situation and its dynamic are an expression of the

current power structures. Research for sustainable development is thus challenged by power in several dimensions: a societal change towards sustainable development might change the present power structures and thus challenge those in power (Strang 2009, p. 11); furthermore, members of the academic policy culture have—through their role as professional knowledge producers—a specific risk of imposing their views on others (MacMynowski 2007). However, if these views challenge the current power structures, the academic policy culture is also at risk to be discredited by other cultures, as can be observed in tobacco or climate change research (Oreskes and Conway 2010).

Expertise

By expertise we mean the substance of knowledge in the broadest sense that is built on or generated for a policy process promoting sustainable development. Following Collins and Evans, a definition of such expertise “needs to be broad, and to include theoretical and practical knowledge from across the range of sciences and stakeholder groups, including the public at large, whilst also emphasizing that ‘democratising expertise’ is not about majority voting in science” (Collins and Evans 2002, p. 280). Collins and Evans use the term contributory expertise for such substantial expertise. Representatives of a policy culture hold contributory expertise to the extent that their knowledge is required for considering and, if need be, bringing forward change towards sustainable development. In principle, all policy cultures might contribute substantial expertise to each of the four stages of the policy cycle.

Complexity challenges for research

Of course, each policy culture is sectoral and functionally structured. For instance, the academic policy culture is divided into scientific disciplines as well as into research groups and funding agencies, among others. Corresponding differences in interest, power and expertise can cause conflicts. At the same time, these differences are the key to understanding complexities to be tackled when providing knowledge for policy processes (Pohl et al. 2010).

The complexity of the science-policy nexus in terms of the way research questions and contents refer to particular policy processes can be disentangled by means of the stages model and the conception of the policy cultures. This allows structuring interactions with representatives of the policy cultures in such a way that the knowledge contributions by research are in line with the respective needs for effectively bringing forward required changes towards sustainable development. A critical aspect in this respect is reflecting on whether and how research can account for interests, power and expertise of policy cultures

when identifying and investigating sustainability challenges, developing policies, implementing them or evaluating their effects. This might include scrutinizing existing forms of social organization (Jerneck et al. 2010).

Knowledge for tackling sustainability challenges

Sustainable development as a strategic issue is about moral choices and the shaping of the required change by policy processes in the broadest sense. Research that is committed to support sustainable development can thus basically contribute to (1) understanding an unsustainable situation, including its genesis and possible future trends; (2) clarifying specific goals or directions of change in accordance with the sustainability core objectives; or (3) designing pathways to bring about the respective changes. Corresponding to these three classes of research questions, three functional types or forms of knowledge can be distinguished:

strategic knowledge, as a scientific contribution to sustainable development, consists of targeted and context-sensitive combinations of explanatory knowledge about phenomena observed, of orientation knowledge [about] evaluative judgements, and of action-guiding knowledge with regard to strategic decisions (Grunwald 2004, p. 151).

The typical notion of scientific knowledge as generic knowledge about facts needs to be expanded considerably to account for the different forms of knowledge inherent in issues on sustainable development or assumptions thereof (Jantsch 1972; ProClim/CASS 1997; Brand 2000; Costanza 2003; Grunwald 2004; Hirsch Hadorn et al. 2006).² In this article, the three forms of knowledge are referred to as (1) systems knowledge, (2) target knowledge and (3) transformation knowledge, following the terminology first introduced by Swiss researchers in a manifest for Research on Sustainability and Global Change (ProClim/CASS 1997, Thesis 7). We use these terms with a further developed meaning (Pohl and Hirsch Hadorn 2007; Hirsch Hadorn et al. 2008).

Systems knowledge

In the context of sustainable development, systems knowledge describes and explains the genesis, the current state and the trend(s) of unsustainable situations in the real world. Systems knowledge typically focuses on

functional structures and causal relationships within or between human and ecological systems (Noelting et al. 2004). It encompasses qualitative and quantitative descriptions, models and explanations of natural or social properties, structures and processes as well as of their dynamic and interrelated nature. Examples are: a quantitative vegetation model of a mountain area; knowledge about the physics and chemistry of soil; knowledge about the relation of property rights, cultivation techniques, soil erosion and farmers' incomes; knowledge about the cultural or religious value of plants in cultivated and uncultivated areas. Systems knowledge may be provided based on systems thinking approaches (Checkland 1994; Schellnhuber 1999; Midgley 2003), as well as, for instance, based on empirical experiments, on climate models, on ethnographic studies or on logical analysis. The feature that makes it part of systems knowledge is that it adds to the understanding of a situation and its dynamic. Because systems knowledge may be uncertain because of a lack of knowledge, inherent variability or unreliable knowledge, research may result in different understandings of the unsustainable situation, its causes and its consequences.

Target knowledge

Target knowledge explains whether certain trends suit respective objectives, and addresses the question of what an adequate direction, frame or orientation for change with respect to the core objectives of sustainability would be. Jantsch (1972) distinguishes between purposive knowledge and normative knowledge, which are two components of target knowledge. In the German literature the term orientational knowledge is also familiar (Mittelstrass 1987; Grunwald 2004; Noelting et al. 2004). Target knowledge consists of the normative reasons required for determining whether situations and practices are judged to be sustainable. Furthermore, it includes knowledge on how to evaluate ongoing processes or states, goals and strategies against the normative concept of sustainability. Examples of evaluation methods are: life-cycle assessments of products, services and production processes; human and ecological risk assessments of substances; sustainability assessments of financial instruments. Examples of reasoning about adequate leeways and directions for change are: studies that concretise and reflect the meaning(s) of the concept of sustainable development for a specific problem at issue; studies that determine critical boundaries of natural and social systems; studies that specify and motivate societal objectives, like, for example, the UN Millennium Development Goals (UN 2000); studies that critically review such objectives or critical boundaries.

² This expansion challenges the divides between the scientific cultures of natural, engineering, medical, and social sciences as well as humanities, among other things.

Transformation knowledge

Transformation knowledge is about transforming current situations and redirecting their dynamics towards sustainable development. It contains the descriptions and explanations of potentials for change as well as knowledge on means for change and on how to develop and use such means. The term action (-guiding) knowledge is also in use (Grunwald 2004; Messerli and Messerli 2008). Transformation knowledge applies to a variety of means: societal change may be triggered by specific technologies; it may require a process of social learning by education and information; a new national or international law; new incentive mechanisms for businesses; a shift in the existing power structures; a shift of cultural norms; a reorganisation of institutions; a change of economic pricing; a tax on international trades (Becker et al. 1999). Transformation knowledge is all the knowledge about such means, their function and the barriers, and opportunities they will encounter. Policy development is basically about determining transformation knowledge.

Complexity challenges for research

Systems, target and transformation knowledges answer different questions about sustainability problems. As all of them are needed for tackling sustainability challenges—be it in the form of sound scientific knowledge, practical know how, explicit or implicit assumptions or other sorts of expertise—all three need to be addressed in research for sustainable development. Research normally rather focuses on one type of knowledge, but implicitly automatically builds on knowledge or assumptions belonging to the other types. For instance, reflecting on the meaning(s) of the concept of sustainable development for a specific problem at issue, which is target knowledge, or designing regulatory means, which is transformation knowledge, both build on knowledge about the behaviour of people, which is systems knowledge. Research that merely implicitly assumes behaviour trends might run the risk of ignoring, for instance, shifts in value orientations of the people due to missing or insufficient empirical evidence. Therefore, it is furthermore crucial to reflect on how to relate and adapt the different forms of knowledge to each other.

For effectively supporting sustainable development it is important that knowledge contributions are not based on inadequate assumptions with respect to any form of knowledge and do not ignore any of them. Distinguishing the three forms of knowledge, identifying the one(s) to focus on and clarifying how they relate to each other allows for making assumptions explicit in order to reflect on them. Furthermore, new insights on one form of knowledge require reconsidering the other forms, as parts of the basis might have changed. For example, a new understanding of

the function of natural and social systems may require reviewing threshold values or targets defined. Also, a modified understanding of specific targets, for instance by giving more weight to future generations, i.e., intergenerational equity, requires different systems knowledge than a stronger focus on environmental integrity.

The framework and its application using a case from research related to land use

In order to approach the challenges research on sustainability problems is confronted with, in an informed way, we suggest structuring the respective core complexity issues into three analytical perspectives (Table 1):

- The sustainability perspective sheds light on (1) existing notions and current debates on how a sustainable development could ideally look in the context of a specific problem situation, as well as on (2) whether and how the general core objectives of this normative societal concept—intergenerational equity, intra-generational equity, and environmental integrity—are covered by them. It helps researchers to adjust their own views and to take adequate interpretations as a basis of their projects. Making these underlying value judgments explicit allows an appropriate handling of the research results and might enrich the process of coming up with shared visions.
- The policy perspective structures the way researchers refer to particular policy processes. The policy perspective allows for reflecting on whether and how research can account for interests, power and expertise of actors of the public sector, the private sector, civil society and academia that are relevant for solving a specific sustainability problem. The policy perspective further helps clarifying whether the knowledge demands refer to identifying sustainability challenges, developing policies, implementing them or evaluating their effects.
- The knowledge perspective finally disentangles the interwoven knowledge requirements for addressing sustainability problems into systems, target and transformation knowledge, i.e., the questions about processes and trends with regard to the way we meet our needs, about where to go and about how to get there. Clarifying what form(s) of knowledge to focus on as well as how to relate and adapt the forms of knowledge to each other allows for making assumptions explicit, including value judgments, as well as facets of problem solving that are unknown and not specifically investigated in a research project.

In the following, the framework perspectives are illustrated using an example of recent basic research in

Table 1 Conceptual framework structuring three key complexity issues research for sustainable development is confronted with into three analytical perspectives with respective structuring elements

Key complexity issues	Analytical perspectives constituting the framework	Structuring elements
Unclear and ambiguous notions and objectives of sustainable development	<i>Sustainability objectives</i> Core objectives	Intergenerational equity Intra-generational equity Environmental integrity
Multitude of actors pushing or hindering development in various interlinked processes	<i>Policy processes</i> Stages of policy cycle Policy cultures	Problem framing Policy development Policy implementation Policy evaluation Interest Power Expertise
Interwoven empirical, normative and pragmatic aspects of sustainability challenges	<i>Knowledge required</i> Knowledge forms	Systems knowledge Target knowledge Transformation knowledge

Ecosystem Sciences related to land use. Note that this illustration is limited to pointing out crucial complexity aspects and does not embrace the full project analysis. In terms of application, the research project aimed at providing policy makers with quantitative information on carbon sequestration potentials and plant productivity in the tropics. It investigated two common land use types, an afforestation and a traditional pasture, using the eddy-covariance technique to continuously measure net ecosystem CO₂ exchange (Wolf et al. 2011a, b).

- The project mainly referred to the vision of restored tropical forest ecosystems contributing to climate change mitigation in the longer term. This goal was set primarily by the international community of states that participate in the UNFCCC process. It seemed to be widely shared by the national environmental authority and presumably also by the national government of the country in which the research was conducted. In terms of the core sustainability objectives, this vision on what to strive for in the context of the global climate problem primarily covers environmental integrity as such, and as a prerequisite for intergenerational equity. It does not address intra-generational equity, however.
- The framework's policy perspective shows that the research project mainly referred to a presumed policy process on the national level for emissions trading under the Clean Development Mechanism (CDM). As

- the knowledge provided by the research project serves as a foundation to assess the profitability of selling carbon credits based on afforestation of traditional pastures, the research contribution can be assigned to the policy implementation stage. The main addressee of the research is the national environmental agency. This authority is certainly a core actor in this stage of such a policy process, namely in terms of providing expertise to the government, representing national interests, as well as having power to influence policy makers. The role of local land users, that are potentially affected by a national afforestation policy because their livelihoods are strongly dependent on grazing land, was well noted but was not included in the scope of the research.
- The knowledge provided describes ecosystem processes and can thus be attributed to systems knowledge. Against the background of the UNFCCC process and the globally available knowledge on carbon sequestration potentials, there is definitely a strong demand for the information provided by the project. In the context of application, this systems knowledge is related to target knowledge, namely to judging land uses that enhance carbon sequestration as better. The project further assumes that national policies or programs restoring tropical forest ecosystems are an effective means (transformation knowledge). Making these pieces of target and transformation knowledge underlying the

project explicit allows for double-checking whether they are appropriate and cover the views of the relevant actors.

As can be seen from this case example, the framework sheds light on complexity aspects that might play a role for the relevance of research inputs to policy processes directed at sustainable development. It reveals on the one hand which aspects have been considered and how, and on the other hand which aspects might have been forgotten in the first place or were neglected for good reasons. This assists decisions as to appropriately engaging with complexity for tailoring knowledge contributions. In the case of the example above, it may confirm that referring to the international climate negotiations and thus providing a very clearly required data set on carbon sequestration potentials of afforestation in the tropics was very valuable. Or it may point out that, from a sustainability perspective, it might be useful to quantify the carbon sequestration potential of a land use system that also secured the local land users' livelihoods, for example, a silvopastoral system. The example also shows the interrelatedness of the three framework perspectives: The sustainability perspective revealing value judgments also points to the local land users as exponents of an additionally relevant policy culture. Similarly, the land users' interests challenge the target knowledge underlying the project, stressing primarily carbon sequestration. These overlaps allow for looking at crucial issues from different points of view and reveal potential assumptions to verify and points to discuss.

Conclusions

Generating effective and substantial contributions to sustainable development challenges researchers to adequately engage with complex realities. The conceptual framework presented in this article structures the respective fundamental complexity issues out of a meta-perspective. It serves as a basis for reflecting on these issues in designing or evaluating research designs. The framework focuses on the contents of research contributions, i.e., the research questions to pose, and therefore does not account for further aspects related to the conduct of research like, for example, institutional and funding related options or constraints.

Adjustments that come into focus when reflecting on a project with regard to enhancing policy relevance may include changes in the very basic assumptions, adaptations of research approaches and methodologies, adding collaboration or exchange with members of other policy cultures, or even shifting scientific norms, if necessary. As the framework has been developed with a focus on natural scientific contributions to sustainable development, it needs

to be validated and empirically tested whether the resulting framework perspectives and their structuring are appropriate for supporting effective research in other fields. Last but not least, working with the framework in research for sustainable development may also help shaping the expectations of the addressees on research contributions, like, for example, getting committed to joint processes of learning instead of waiting for ready-made solutions. We argue that meeting the complexity inherent in the concept of sustainable development requires joint learning in policy processes, working out shared visions being in line with the core objectives of sustainable development and generating knowledge about empirical, normative and pragmatic aspects.

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