Advancing sustainability science in South Africa

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SCIENCE HAS CONSIDERABLE POTENTIAL to contribute to sustainable development. Much of this potential remains latent, however, due to the divisions that exist within and between the producers of scientific information and the users of this and other sources of knowledge. A response to this situation has seen the emergence of 'sustainability science', which aims to overcome divisions between knowledge sources of various forms, including the social and natural sciences and alternative epistemologies that warrant acknowledgement. We review the key defining characteristics of sustainability science, and describe some examples of science-based South African initiatives, aimed at promoting sustainable development, that incorporate many of these characteristics. We suggest that, with some reinforcement of their sustainability science base, these examples provide good templates for broader application. To retain the experience gained through such projects and to build organizational memory, there is a strong case for the establishment of transdisciplinary centres for sustainability science in South Africa.

Introduction

In sub-Saharan Africa, the consequences of the failure for sustainable development to materialize are very apparent. This is illustrated by the fact that 45% of the population is classified as extremely poor, which is the highest percentage in any region globally.[1] Unlike the trend in other developing regions, where levels of extreme poverty are in decline, sub-Saharan Africans are also getting poorer.[2,3] This situation is paradoxical given the relatively intact state of the region's natural resource base, which has the potential to support sustainable development.[4,5]

South Africa is somewhat better-off than many sub-Saharan African countries in terms of its state of development. The annual growth rate of the economy in real gross domestic product (GDP) at market prices for 2005 was 4.9%, which reflects an increase in the average real GDP growth rate achieved, for example, between 2001 and 2005.[6,7] In realizing this economic performance, it is uncertain what trade-offs there are, measurable in terms of social costs and threats to the delivery of ecosystem services in the long term.[8] In this regard, for example, the social costs (mainly health-related) of coal-based energy supply to industry are high, exceeding the direct expenditure on energy by the industrial sector.[9] An unemployment level of around 27% in September 2005, and a decreasing trend in the Human Development Index over the last decade, are also key issues constraining sustainable development in South Africa.[10]

Modern science has been perceived as having great potential to promote human well-being in the long term by producing information to support decision-making.[11–14] Although the rate at which humans are altering the environment largely exceeds the rate at which we fully understand the consequences,[15] science has proved capable of accurately predicting many of the outcomes of human development. For example, some implications of global warming associated with the combustion of fossil fuels have been predicted by scientists for decades.[16] Also, science has accurately forecast the collapse of overexploited, renewable natural resources, such as fish stocks.[17] With its obvious power to inform decision-making, why then has the scientific community, or perhaps the users of scientific knowledge, had limited success in implementing the concept of sustainable development? Although there is no simple answer to this question, we believe that the origin of many challenges for sustainable development lies within and between the divisions amongst the 'producers' of scientific knowledge and between the 'users' (for example, business sectors, local communities, government decision-makers) of this and other forms of knowledge. This situation is compounded by the diverse range of value systems, for example political and economic self-interest, that influence decisions and behaviour.

Divisions of this type are commonly attributed to a Cartesian dualism through which the world is perceived in separated subjective and objective realms.[18] A perceived incommensurability between objective and subjective forms of knowledge is one consequence of this. Such divisions also reflect more directly the tension that exists as a result of merging two sustainability concepts into the single ideal of sustainable development. The first concept, which is largely underpinned by the natural sciences, is that of 'ecological sustainability'. This notion was developed mainly in western countries in response to the effects on the environment of growing levels of consumption and production associated with post Second World War industrialization.[19–21] These concerns are documented in several keystone publications.[22–24] The second concept, which is largely underpinned by the social sciences, economics and development planning, emphasizes the urgency of economic and social development to address issues of regional poverty in order to promote sustainable development globally. This was the focus, for example, of the Stockholm Conference on the Human Environment (1972) and the Rio de Janeiro Earth Summit (1992), and is documented in publications such as the *World Conservation Strategy* and *Our Common Future*.[25,26] This 'conservation–development' dualism counteracts the process of integration between, for instance, ecology, economics and sociology, and explains the many discordances that exist between scientific disciplines and political decision-making. These discordances prevent adequate understanding of the consequences of human developments that impact upon ecosystems, and the adaptations that humans make in response to these impacts.[27] Economic considerations tend to dominate over the other aspects of sustainability (for example, maintenance of environmental integrity or the achievement of broad social equity) when trade-off decisions are made.[28]

This article introduces some emerging ideas around how science might better contribute to sustainable development in South Africa by the potential it has to bridge the divisions we have just described. These ideas are grounded in what has quite recently been defined as a new contract between science and society that defined by 'sustainability science'. Our aim is to define sustainability science within the South African context as a basis for its subsequent development and application.

Some defining characteristics of sustainability science

The 2002 World Summit on Sustainable Development (WSSD) was catalytic in terms of triggering a range of scientific initiatives aimed at promoting, or elucidating, the concept of sustainable development through this political forum. In the South African context, the WSSD took place in the wake of endeavours focused

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on integrating science and development policy in support of sustainable development. For example, the Cape Action Plan for People and the Environment, which presents a long-term strategy for biodiversity conservation within the Cape Floristic Region (CFR), was groundbreaking in terms of its integrated approach to biome-scale conservation planning and analysis of economic and social aspects of ecosystem services derived from the CFR.[29–31] South Africa's Working for Water Programme illustrates the integration of research and management in the control of alien invasive vegetation, with the aim of increasing water production from selected catchments whilst simultaneously providing employment and alleviating poverty.[32] The WSSD was also used to showcase the potential of complexity modelling as a tool for gauging the sustainability of alternative development scenarios in South Africa.[33]

The summit served as a reminder that the transition from unsustainable to sustainable development trajectories requires much more from the social contract that has long existed between society and the science community.[34] It triggered ideas for increasing the effectiveness of science and adjusting its traditional mode of conduct towards one more capable of promoting sustainable development. Significant in terms of translating rhetoric into ideas for a practical research agenda was a meeting, convened at Sweden's Friibergh Manor in advance of the WSSD, at which notions about what was defined as sustainability science were developed.[35] Subsequently, these ideas have been further refined and tested, in parallel with similar initiatives.[28,36]

The emergence of sustainability science can either be perceived, in the Kuhnian sense, as a revolutionary approach to enabling science to contribute more effectively to sustainable development or as an evolutionary shift, based on a Popperian explanation.[37,38] It is not important to make this distinction here; however, we believe that Kuhn's explanation of how post-revolutionary, normal science becomes established and practised provides a useful framework for defining our understanding of the central features of sustainability science and the early stages of its trajectory of theoretical development and practice. Our understanding is derived from a review of the international and South African literature and interaction with leading theorists and practitioners of sustainability science.

Sustainability science is built around several central features or consistent trends, which Kuhn would describe as fundamental properties that provide a basis for the initial practice of a newly established sphere of science.[37] Collectively, these provide general methodological prescriptions, standards and instrumental techniques that promote a coherent approach to research and problem-solving.[39,40] Although, in the case of sustainability science, the following defining features, which we discuss below, are still emerging and do not yet reflect an established, coherent body of practice they can be identified as elements in the international debate in this area:

- Use-inspired basic research;
- location at the interface between human society and its sustaining natural environment;
- focus on the resilience of complex social–ecological systems;
- transdisciplinary approach to understanding system complexity and resilience;
- acknowledgment of the validity of multiple epistemologies, extending beyond the objectivity of science to include the subjectivity of alternative knowledge systems; and
- emphasis on learning and adaptation.

Sustainability science defined as 'use-inspired basic research'

Harvard University's Center for International Development defines sustainability science as 'use-inspired basic research' that seeks to learn about interactions among humans, their technologies and the ecosystem services that sustain them, and to apply this learning to address urgent problems of economic and social development, as well as environmental management.[36] This definition is aligned with what Stokes defines as research that is motivated jointly and simultaneously by a desire to discover generalizable knowledge and to select research questions arising from a concern to resolve the practical problems of the world — where the resolution of such problems lies beyond the competency of any single scientific discipline.[41] A key challenge in this regard is to balance the traditional aim of scientists, which is to obtain basic knowledge that is regarded as universally true and having a multi-scale perspective (that is, local, regional and global), against the need for knowledge that may be applicable only to specific places and contexts.[35,42,43] This introduces a novel dimension to sustainability science, which extends its definition beyond what may be regarded as traditional applied research.

Sustainability science is research that produces knowledge that is immediately useful for policy and management. It therefore has as its goal the integration of science and technology with other sources of knowledge to solve problems and to inform decisions. This requires operating within a 'knowledge system' comprising networks of linked actors broadly classified as producers and users of knowledge; that is, both the problem to be solved and the knowledge needed to solve it are defined collaboratively in the conduct of sustainability science.[44] Illustrating this are key sustainability issues linked, for example, to the Millennium Development Goals, the New Partnership for Africa's Development (NEPAD) and South Africa's Integrated Development Plans.

Sustainability science focuses on the interface between human society and the environment upon which societal well-being depends. In this context, sustainability science aims to improve understanding of how society shapes the environment and how the environment, in turn, shapes society.[36] In the context of sustainability science, reference is made to 'social–ecological systems', which are viewed as ecological systems that are intricately linked with and affected by one or more social systems.[45,46] Some related definitions interpret humans as being part of natural systems, with any division between social and ecological elements regarded as being artificial.

Understanding the resilience of complex social–ecological systems

Systems thinking, which evolved partly in the course of developments in the biological sciences, is found in many different disciplines, including economics, management sciences, engineering, art and philosophy.[47] Underpinning the systems approach is the concept of 'holism', a term created by Jan Smuts, the South African politician and philosopher, and used in the title of his book *Holism and Evolution.*[48] Smuts's 'holism', in opposition to a mechanistic view of the world, assumes that natural wholes are more than the sum or mere aggregate of their parts. Aldo Leopold, in his book *A Sand County Almanac,* presents a similar view, also incorporating humans into this 'whole', which he describes as the biotic community.[49]

Complex social–ecological systems have emergent properties that are influenced by, but cannot be reduced to, the characteristics or properties of their parts.[50] The non-linear nature of system processes and feedbacks, different scales at which these operate and cross-linkages between systems are some of the factors that explain their complexity.[51] Faced with this complexity, a shift is occurring in the focus of system analysis from prediction and control to understanding a system's 'resilience' in order to provide a foundation for adaptive system management.[52]

Social–ecological system resilience is defined as the capacity of a system to absorb disturbance, including major shocks (such as droughts, war), and adapt to change so as still to retain the same function, structure and identity.[53] It relates to the ability of systems to tolerate disturbance without collapsing into different states (e.g. grassland to desert, democracy to dictatorship) controlled by different sets of processes.[53–55]

Adopting a transdisciplinary approach

Mebratu describes the response of the scientific community to the challenges of sustainability research as having occurred in three phases.[56] The first phase is defined as the 'disciplinary' response, whereby each scientific discipline aimed to analyse particular sustainability issues from within their separate domains. However, none of the main problems of sustainable development can be dealt with through scientific disciplines operating in isolation.[57,58]

The second phase of response by the scientific community acknowledged that the challenges of sustainable development are extremely complex and require resolution through combined contributions from many disciplines. However, the effectiveness of the resultant multi- and inter-disciplinary research is limited by the difficulties that scientists from one domain experience in understanding the concepts and languages of another, and the retention of shortcomings of the tools and concepts applied within the various scientific disciplines within the combined research outcome.[56] Synthesis in science is not achieved through accumulation of multiple scientific outputs. It requires much more than this, which explains the recent emergence of a third, 'transdisciplinary', phase of response within the scientific community.

Max-Neef refers to the functioning of transdisciplinarity across and between four hierarchical layers.[57] Two of these layers include the objective domains of science, such as mathematics, chemistry and ecology, and the technological disciplines through which associated knowledge is applied, for example, engineering and industry. The other two hierarchy layers include the subjective and normative dimensions of society pertaining to value and ethical issues such as the ends to which scientific knowledge should be applied and the institutional settings through which this is effected, for example, planning, politics and law.

Transdisciplinarity, in the form in which it is incorporated into sustainability science, promotes effectiveness in joint problem identification and solution by scientific, societal, economic, political and other stakeholders.[59] It strives to reverse divisions of various forms, including those that separate empirical (for instance, ecology, economics) and normative (such as politics, law) discourses.[56] This requires dialogue both within the scientific community and between this community and stakeholder groups, such as business, politicians and society in a common process of problem identification and resolution.

Validity of multiple epistemologies

Sustainable development is a value-laden concept that moves beyond defining what exists, in the physical environment, to what the relationship between humans and this physical environment should be.[28,60] Sustainability science, therefore, operates within a social and ecological context, in which endorsement and use of the knowledge that it generates depends on how effectively it can navigate multiple societal worldviews.[61] Sustainability science cannot exist outside of the many normative (that is, value) aspects of the social–ecological systems to which it applies.[62] It requires more than engagement of the scientific mind; engagement with the subjectivity of stakeholders is also required.[28]

Sustainability science must be flexible enough to accommodate different forms of knowledge and worldviews.[61] In doing so, a response is required to the tension that can exist between the perceived validity of science, which is typically embedded in a particular cultural–historical context,[63] versus that of other knowledge forms. Whilst traditional science can validate some forms of alternative knowledge (such as subjective knowledge), this is often not possible and trade-offs need to be made.[61] Mitigating this situation requires properly structured dialogue that will reveal knowledge tensions, which in some cases may be attributable less to differences in material interests than to differences in how these interests are framed and problems are understood.[64,65]

Science that enables 'learning and adaptation'

Through sustainability science, there is a shift from the traditional goal of 'knowing' towards a goal of continual 'learning and adaptation'.[43] This shift acknowledges that there is much about complex social–ecological systems that is not understood and which will always need to be learned in order to advance the management of such systems. Sustainable development is assumed to be a process of adaptation and social learning, with knowledge playing a central role.[43] This is particularly significant given that current rates of social and ecological change fall outside any human historical experience.[28]

Sustainability science is evolving to emphasize action and social learning in addition to the traditional scientific approach of hypothesis formulation, observation, verification, understanding and prediction.[42] Through adaptive management, policies become hypotheses and management actions become the experiments to test these hypotheses.[66,67]

Sustainability science: enabling its practice

Following the comparatively recent emergence of sustainability science, there has been a period of consolidation of its theoretical basis. In the Kuhnian sense this has produced an initial, very loose set of 'rules' that have been formulated in order to extend its application within the community whose allegiance it has secured.[37,40] However, these rules are not easily derived from exemplars that can demonstrate the practical application of the theory.[61] Whilst broad agreement on the defining attributes of sustainability science that we have just described and what it aims to achieve is emerging, the debate on how sustainability science should be practised in order to achieve these aims is still in its infancy.

Many social–ecological systems within South Africa are currently transforming into fundamentally new ones. This has been triggered by a range of processes, some relatively slow-moving and global in character, such as climate change, and others more immediate and local, such as South Africa's recent democracy. In order for sustainability science to develop beyond its conceptual definition and make an impact on sustainable development in this country, it is important that there is development within three main fronts to the debate regarding its practical application. These can generally be defined in terms of organizational structures, processes, and tools for sustainability science. We limit the discussion that follows to an overview of some examples of organizational structures through which sustainability science is practised globally and which may be suitable for local replication.

Traditional organizational structures established to serve both the producers and users of scientific and other knowledge exist in a relatively fragmented state. This presents a significant obstacle to transdisciplinary research and the exchange and application of knowledge in support of sustainable development. This fragmentation is illustrated, for example, by the separate characters of South Africa's science councils, the CSIR, the Council for Geoscience, the Human Sciences Research Council, the Agricultural Research Council and the Medical Research Council, which are some of the country's largest research institutions. Similar to the general global pattern, these divisions are replicated within our university structures by the marked separations between different scientific disciplines.[57] These are particularly evident between the natural and social sciences. A similar pattern exists across the country's public sector structures, which is compounded by the arrangement of tiered national, provincial, and local authorities.

In spite of the state of fragmentation we have just described, several good examples of projects incorporating many of the elements of sustainability science can be cited. In most cases these projects can be defined in terms of their focus on complex sustainable development issues and the transdisciplinary analysis of the social–ecological systems in which the issues arise. The Southern African Millennium Ecosystem Assessment, which provides information on the relationship between ecosystem services and human well-being in the subcontinent, in order to promote sustainable development at various scales, is outstanding in this regard.[4] South Africa's new water policy, which was developed through a largely unprecedented degree of collaboration between disciplinary scientists with various institutional affiliations, government and society, is another example (see Box on this page).[68,69]

A review of selected, established centres undertaking progressive research on sustainable development indicates that they share a number of defining features. Notable in this regard is their solutions-orientated approach to promoting sustainable development. This implies a close connection with the politics of problem definition; that is, they take it upon themselves to build bridges for dialogue and interaction with the potential users, including political institutions, of the knowledge they generate.[75] In the U.S., Arizona State University's Global Institute for Sustainability (GIOS), the University of Wisconsin's Center for Sustainability and the Global Environment, and Harvard's Center for International Development are examples of research institutions that have adopted this mode of operation. A similar situation applies in Europe, for example, Sweden's Stockholm Institute, and in Australia, for instance, the CSIRO.

A general feature of many centres of sustainability science is the relatively small size of their tenured leadership and core administrative teams. These typically comprise a few leading, well-networked 'interstitial scientists' with insight into and political connection with the sustainable development issues upon which the research centres focus. Research teams of variable size are assembled on a project-by-project basis, with the range of disciplines and relative contribution of each determined by the scope of project research that is required. Team members, who maintain their specialist skills within various 'disciplinary home bases', are targeted for the specific expertise they can contribute in collaboration with others. In creating teams, attention is given to the balance between natural and social scientists and between these scientists and knowledge users, who are also targeted according to their ability to contribute as team members. In this latter regard, for example, Arizona's water resource management authority is integrally represented in research teams, focusing on water-related research projects coordinated by the GIOS.

This article has outlined several South African examples of projects reflecting some of the elements of sustainability science. In most instances, however, these have been undertaken within a loose organizational structure that exists for the duration of the project's lifetime. A

South Africa's water policy: An example of sustainability science?

Following South Africa's democratic elections in 1994, social equity and the need to redress past inequities emerged as key political priorities. In terms of water resource management, this took the form of the challenge to provide basic water and sanitation services to the majority of South Africa's population, and to ensure equitable access to water for all people.[70] The challenge was both strongly 'use-inspired' and located at the 'interface of human society and an ecosystem service' that is essential for development and societal well-being over the long term.

All policy and legislative systems in South Africa are subjected to scrutiny and review through processes of public participation and consultation. These participative approaches to the formulation of policy and law, which also characterized the reform of South Africa's water policy and associated laws, are now enshrined in South Africa's new constitution.[71] Two central tenets of the constitution are that people should participate in decision-making and that national government mandates are most effectively carried out by the lowest appropriate levels of government.[71] These tenets underpin the generic principles of good governance: openness, participation, accountability, effectiveness, coherence, democracy and integrity.[68] The principles are also aligned with two of the defining characteristics of sustainability science relating to the recognition that is afforded to 'multiple theories of knowledge', which emerge through the process of stakeholder engagement, and the importance of 'transdisciplinarity' as a means to integrate knowledge originating from the natural and social sciences as well as other sources, such as local communities and implementing agencies.

In the water sector, the outcome of the processes of public participation and engagement with all sectors of society led to the development of the country's new water policy.[71] In turn, the water policy provided the framework for the promulgation of two key pieces of legislation, namely, the Water Services Act and the National Water Act.[72,73]

In contrast with the situation in many other countries, South Africa's water policy contains explicit recognition of the mutual interdependence between society, economic development and sustainable water yield.[70] The policy's acknowledgement of this interdependency indicates its perception of society, and the natural-resource base upon which societal well-being depends, as comprising a complex social–ecological system. Reflection of this in law, in the form of the National Water Act, makes the act one of the most advanced and forward-looking pieces of water legislation in the world.[74]

Since South Africa's water policy has only recently been put into effect, it remains to be seen whether feedback from its early implementation results in its adaptation, such that its practical effectiveness is ensured.

consequence of this, is that upon completion of the projects there is little accumulation of organizational memory through which learning can be easily extended to other applications. This limits the distribution of learning that is gained and does little to promote the wider application of such learning. As a necessary condition for the broader practice of sustainability science, we believe there is a strong case for the establishment of transdisciplinary centres for sustainability science in South Africa. The general features of leading international centres of sustainability science provide good models for adaptation in South Africa.

Conclusion

The traditional disciplines within the natural and social sciences are important for informing decisions that can change the current course of global development towards one that is sustainable. However, more effective integration between these two broad spheres of knowledge is required if social–ecological systems are to be properly understood and maintained. In addition, policy-makers and implementing agencies play a critical role in promoting sustainable development, but are often isolated from essential sources of knowledge necessary to do so prudently and effectively. The transdisciplinary approach of sustainability science can assist in bridging these divides.

Various constraints hamper the effective practice of sustainability science both globally and in South Africa. These include: the high degree of specialization within separate scientific disciplines, which makes interdisciplinary dialogue and communication with non-scientists difficult; the separate characters of the country's research institutions (especially the science councils and universities); and the functional divisions within and between spheres of government. These barriers to transdisciplinarity constrain our understanding of South Africa's complex social–ecological systems and our collective ability to manage them in a sustainable way.

A core competency of sustainability science needs to be established and a strongly networked, broader community of practice built around this competency. We propose a 'learn-by-doing' approach, focusing on projects that address key challenges to sustainable development in South Africa, as the best way to achieve this. This could be illustrated by a project to evaluate the implications of alternative energy futures on the resilience of South Africa's social–ecological systems. Some research institutions in South Africa are in the process of building capacity in various elements of sustainability science; for example, resilience theory, complexity theory, and transdisciplinarity. This is a desirable development and one that will be enhanced through the development of collaborative networks between these institutions. A key challenge in the current initial phase of establishing sustainability science in South Africa is to secure the involvement of political and other non-scientific stakeholders (especially business and industry) in making these networks effective.

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