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Sustainability science: Which science and technology for sustainable development?

Joachim H. Spangenberg

Sustainable Development

Research for sustainability must be clear about what sustainability is all about -- otherwise, without a substantial understanding of the subject matter at stake, research would strive to answer questions which may have not been asked and which might even not make any sense in the sustain ability context. So what is sustainable development?

The concept of sustainable development has emerged as a new paradigm during the last decade. The definition most frequently referred to is the one provided by the Brundtland Commission's (officially the WCED World Commission on Environment and Development), characterising it as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" , p. 43). This definition has been publicly denounced as vague, imprecise and not operational. However, it has helped to put sustainable development on the international policy agenda, making the concept a vision so impossible to ignore that all kinds of interest groups are actively battling for hegemony regarding the definition. No surprise then, that the approaches suggested lack any common definition or operational principle: a common definition of sustainable development needs to cover a broad range of interests which have no easily identifiable common denominator.

So it is not the vagueness of the WCED's suggestion, but the conflicts of interest which cause the somewhat murky picture of what sustainability is all about. However, the Commission's definition already includes all key elements of sustainable development in a nutshell.

First of all, sustainable development is not a positive but a normative concept, ethical rather than analytical. It demands intergenerational justice to preserve the freedom of choice for future generations, regardless of what their attitudes and preferences might be. Secondly, it demands that the "need of the present" should be met, including all humans on Earth, and not restricting needs to economic or basic ones. Thus the Brundtland Commission's ethically based pre-analytical vision or grand narrative is to provide to everybody everywhere and at any time the opportunity to lead a dignified life in his or her respective society. This is assumed to include a decent standard of living, social cohesion, freedom in an open and participative society and a healthy environment. The three core imperatives derived from the problem areas are :

- the environmental imperative: safeguarding the environment,
- the social imperative: realising justice between people, countries, gender, social groups etc, and
- the institutional imperative: securing political participation.

An economic imperative is not mentioned. Instead, the economy is perceived as Janus-headed, exhibiting deep ambiguities: it is a driving force behind most of the problems, as well as a potential force for the better, contributing to the solution of problems by creating enough wealth to solve them. In a similar fashion, science and technology are increasingly recognised as central both to the origins of the sustainability challenges, and to the prospects of successfully dealing with them.

The Challenge to Science and Engineering

Facing the "*triple P sustainability challenge*" of *poverty, pollution and participation deficits* means that science must striving to understand both the natural and the cultural World and the way they interact in order to help find ways out of the sustainability crisis. This includes helping to map out the choices society faces and their consequences, while not confusing means and ends, i.e. being clear about the fact that the choices we face are societal choices, not scientific or technical ones.

As a normative concept including social, economic, environmental and institutional objectives sustainable development is perhaps the most fundamental challenge to the concept and institutional system of modern science that ever emerged since the Romantic period. So far the scientific community was used to set its own agenda, irrespective of the problems concerning the society at large (except those articulated by granting public or private research funds, of course), and steadily developing into an agglomeration of more an more specialised, rather unconnected disciplines and schools of thought. At the same time, the sustainability discourse offers immense opportunities to reconnect science to society and to build a new basis of public support for research and development as a key precondition for both science and society to flourish.

The imperatives mentioned have been defined in order to generate solutions to four themes identified as key societal problems under the sustainability paradigm :

- the environmental challenge: the global degradation of the natural basis of human life,
- the first social challenge: the increasingly unequal distribution of income and assets in and between countries,
- the second social challenge: the high number of people living in poverty, and

- the institutional challenge: the resulting threats to peace and security.

These challenges are neither based on one core problem nor independent but interlinked. They have to be dealt with simultaneously rather than consecutively due to the very urgency of the problems. Both these facts give reason to approach sustainable development as a dynamic optimisation process across the four dimensions (social, environmental, economic and institutional) of sustainable development. Sustainability research thus has to contribute to

- the integration of economic, social, environmental and institutional research issues into a coherent framework of interacting complex systems, safeguarding the essential interests of each dimension (not necessarily each discipline), as far as possible in synergistic was to save scarce (intellectual just as financial) resources,

- the (re-)introduction of normative targets, in particular concerning distributional justice in and between countries as highly relevant research topics into economics, ecology, sociology, political sciences, trade, development and other research, and

- the extension of the research perspective to include distant regions and future generations, monitoring and assessing the impacts of our more sophisticated, far reaching and enduring interventions into natural and social systems, in particular since in many cases our understanding of the systems affected lags behind our interventions (stop "throwing stones farther than we can look" by learning to look farther).

While the integration condition requests transdisciplinary research to identify synergies and trade offs between the systems and issues concerned, the normative target rules out all solutions involving the generation of externalities to be passed on, as the global and intergenerational perspective demands a new approach towards boundary setting in analysis and impact assessment.

Science for sustainability is science which meets these criteria while contributing to solutions for the most urgent sustainability problems as defined by society, not by science. It represents an effort to empower all members of society to make informed decisions, thus representing an idea of the "knowledge society" going far beyond technical means of communication. Sustainability science needs to include and build upon natural, technical, social and economic sciences, but has to integrate and reshape them to accommodate the needs of the sustainability paradigm.

Sustainability Science: In Search of a Shared Vision

Sustainability science supports the quest for sustainable solutions in a complex world characterised by factors which may be generated locally, but with their impacts affecting people across countries and generations. They include for instance:

- the globalisation of communication, culture, finance and economies, and the resulting dependency of states, economies, nations and cultures on factors beyond their control,

- a global environmental crisis in need of monitoring, assessment and rapid preventive and adaptive measures. Such problems include the rapid a and largely irreversible transformation of the land, the increased carbon emissions causing climate change and the long-term threat of nuclear waste from civilian and military uses, overexploitation of scarce water resources and salinisation of aquifers, or the loss of biodiversity and the risk of destabilising populations by the release of genetically modified organisms,

- the North-South divide in income, life expectation, health service provision, research capacities (resulting in a path-bound development of scientific research and technology development on mostly Northern demands) and economic, social and environmental vulnerability,

- a lack of gender balance in society as well as in science and engineering, depriving societies of a most urgently needed resource, the knowledge, experience and initiative provided by women,

- a World with an urbanisation of more than 50% by 2020, causing all kinds of local social, economic, environmental and governance problems.

Science-based interventions in complex natural and social systems can constitute, in themselves, a self-renewing source of problems. Science for sustainability needs to counteract these challenges by issue-driven and reflexive research, beyond the prevailing curiosity-generated or mission-oriented work. This includes reducing vulnerability through the implementation of early warning systems and the development of suggestions for effective prevention strategies and adaptation measures, including if necessary restrictions to the use of scientific insight and technological capabilities. It needs to support policy implementation and enforcement by developing effective monitoring mechanisms, and it should provide examples of problem solving, for instance by setting standards for gender equity, North-South co-operation and a problem-solving research focus within the scientific community.

Sustainability science cannot but be complexity science, dealing with the interaction of multiple-complex, dynamic, non-linear, self-organising systems under conditions of irreducible uncertainty. This poses challenges for the analytical and methodological development work, including the generation of appropriate tools for theoretical model generation and empirical analysis. In order to do so, sustainability science has to explore new knowledge and effectively apply existing knowledge, although in a reflexive manner taking into account cross-system feedback loops and rebound effects, time gaps, non-linear and threshold effects, multiple system equilibria and the irreversible lack causal explanations. As the effects to be taken into account will frequently emerge outside the individual scientist's realm and field of competence, making it urgent to overcome the old-fashioned conception of scientific communication as one-way traffic of information from experts to decision makers and the public at large has to be replaced by a notion of partnership through reciprocal learning by all those involved and affected. This means a deep involvement of the public and decision makers into the quality assurance and assessment of scientific and technological innovation: every stakeholder becomes a peer.

As the problems analysed, science for sustainability must cross disciplinary borders. This implies not only involving different disciplines in the course of research, but going beyond specialised scholarship towards "transdisciplinary research" by involving all appropriate disciplines as well as representatives of relevant non-scientific knowledge in the definition of the problems to be analysed and the lay out of the research work to be undertaken. Integrated approaches addressing multiple goals based on *all* kinds of knowledge available are a necessity in a research field consisting of multiple interacting systems, each of them bound to certain sustainability objectives. In this sense, sustainability science must be post-normal public science, defining research questions relevant to society and identifying solutions resonating with decision makers. The results must be reliable enough for people risking to act upon, and they must have immediate meaning to decision makers in order to be applied in practice. Science and technology are most effective when research and development are undertaken in close collaboration with stakeholders and users, in particular with decision makers in administration, politics and the business sector. This calls for an improved dialogue of science, engineering, politics and civil society, but this kind of new partnership needs to be based on new orientations towards global responsibility, not least of science and amongst scientists.

Cross Cutting Challenges

The strengthening of nations' scientific capability is an important contribution to sustainable development. However, this capacity should not just follow "the trodden path of science" but be developed with a clear emphasis on the challenge posed by sustainable development needs. The promotion of science for sustainable development thus requires procedures for evaluating science and technology contributions against criteria for sustainability. Neither the advance of science and technology itself nor the current widening of competitive markets can be expected to promote, as if 'naturally' a path of sustainable development. On the contrary, the short-term orientation and the mixtures of commercial, military and other preoccupations that motivate much of the science-based technology development are most often controversial to a sustainability perspective based on peace, justice and environmentally sound development . There is an undeniable risk of under-supplying public goods essential to sustainable development when too much of the R&D talent is in private hands, and focused on delivering private value.

Research for sustainability has to take into account the fact that social, economic and environmental systems are dynamic and interlinked non-equilibrium systems, and to adapt basic assumptions of the research agenda accordingly. Technology development should be twinned with technology assessment, both taking into account the complex setting the artifacts they deliver will work in and the complex set of demands they will be confronted with throughout the design and development process, including not only effective functioning and economic viability but with the same importance the side effects on social and environmental systems all too often ignored and externalised. Conceptual understanding is a precondition for practical solutions, but reliable baseline data and concepts are just as important. They are the means of testing and if appropriate falsifying the concepts. The move from case studies and pilot projects to a body of comparative, critically assessed and evaluated knowledge to be expanded through the interaction of theoretical reasoning and empirical application is an essential step towards understanding the sustainability challenge. Given the global challenges, sustainability science must be global in its outreach as in its participation, including capacity building to narrow the knowledge divide.

To promote sustainability there needs to be explicit identification of the kind of future socio-economic order that societies wish to strive for, and a permanent social learning process in pursuit of these goals, involving scientists and engineers as all other members of society. To make best use of this continuous learning process, changes introduced by science and technology as well as their effects should be as far as possible reversible rather than establishing bifurcation points and initiating irreversible, path-dependant developments. An error-friendly design and management of technical and social systems might help to safeguard the self-determination of societies in times of rapid, technology driven change. Error-friendliness combines two characteristics: error tolerance to accommodate human mistakes, and error driven learning mechanisms as a means of permanent improvement.

If science is to contribute effectively as a force for sustainable development, clear criteria must be set and priorities developed within the scientific community and its donor groups. However, this requires changes in both demand for and supply of sustainability science. On the supply side, this involves renovations of disciplinary approaches as well as innovative research covering new ground in dealing with crosscutting issues of several systems (economic, social, institutional, and environmental). The International Council for Science has identified three core themes:

- *adaptiveness, vulnerability and resilience in complex socio-ecological systems:*
  Sustainability depends on building and maintaining the adaptive capacity needed to deal with the shocks, surprises and longer term structural transformations that are increasingly characterising our world. Existing understanding of adaptiveness, vulnerability and resilience has tended to adopt either nature- or society-oriented views of the world. What is needed are new concepts including the interaction of society and economy, value systems and power structures and their interaction with environmental systems and sustainability objectives.

- *sustainability in complex production-consumption systems:*
  There have long been calls for deeper understanding of how the environmental impacts of production, on the one hand, and consumption, on the other, can be lowered. An important insight is that the greater need is for an integrated understanding of the relations between consumption and production. Neither are consumers driving the economy from the demand side, nor are businesses independent from them. Habits, attitudes and preferences of consumers and producers shape the global production chain, with sustainable development an explicit objective on either side. Unless quality of life and sustainable consumption cannot be reconciled, consumers will show reservations, and as long as sustainability provides no opportunities for more or more secure profits than unsustainable behaviour, business will remain opposed to the concept. Social and economic sciences must contribute as much as natural and technical sciences to the solution of these problems.

- *institutions for sustainable development:*
  The systems of rules, procedures and orientations that guide social interactions shape both the challenges of, and the opportunities for, sustainability. Even

anecdotal experience clearly demonstrates the limited ability of our institutions to deal with the long-term challenges, normative targets and the cross-scale aspects of sustainability. While education and capacity building will be essential bridge the knowledge gap between what we know and what we need to know, new transdisciplinary approaches will be necessary to generate the relevant knowledge. Monitoring systems regarding the sustainability performance of institutions and governance models are only in an embryonic state, and existing indicator systems tend to ignore core aspects of cultural diversity, power structures and in particular gender discrimination. Gender mainstreaming in scientific staff and research topics offers a significant potential for enhancing the human knowledge base.

Not only the definition of innovative fields of research and development is a challenge to the established disciplines, but even more so the demands resulting from the necessary collaboration of scholars from different schools to solve problems of sustainable development. First of all, it means accepting the limitations to one discipline's contribution and the dependency on others. This leads to dealing with research questions formulated in other than the disciplinary language and thus probably out of reach for the established instruments. Consequently, for any school of thought integration into the sustainability framework means admitting limited competence, acknowledging the importance of heterodox schools of thought and questioning its own basic concepts and assumptions regarding their suitability in an extended framework. For different disciplines -- here in alphabetical order -- this has different implications; for instance:

- In *biology*, more attention should be devoted to the two-way interaction of humanity / society / economy and nature in systems evolution, and the development of capabilities like intelligence. Despite the importance of understanding genetic mechanisms, genetic determinism cannot explain the behaviour of higher level complex systems like individuals and ecosystems.

- For *chemistry*, not only the environmental impact of chemicals needs to be monitored and reduced, but substance development must go together with life cycle wide impact assessed including a limited mobility and durability of substances in line with the capacities of monitoring systems and the development of materials tailor-made for reuse, recovery and recycling.

- In *ecology*, the reaction of systems to increased levels of material and energy throughput required additional attention, and the perspective needs to be extended to include the role of governance models for effectively minimising the resulting damages.

- *Economics* needs to shake off the dominance of microeconomic thought -- otherwise sustainability as a global and intergenerational normative concept cannot be accommodated. Sustainability needs concepts and S&T in the service of public sustainability goods like a healthy environment for future generations (i.e. an undiscounted future), human health, full employment, fair income distribution, education and workers rights. For this behalf, accounting must go beyond monetary accounting to include physical and social measures. As a multi-dimensional concept, sustainable development has no unambiguously defined optimum, as it is usual in economic theory when only two competing targets are taken into account.

Instead, criteria must be defined to distinguish potentially sustainable from definitively unsustainable development trends. The research focus needs to shift from equilibrium models to understanding complex systems with multiple equilibria and unstable states. This would be supported by updating the perception of humans to the state of psychology and anthropology, including complex behaviour determined by social interaction as much as by individual utility maximisation.

- *Medicine* must devote a larger share of the research work to combating Third World diseases, but even more so to develop health promotion strategies based on the WHO's broad definition of health, including poverty eradication.

- *Political science* usually does not take note of the physical basis underlying nations, economies and trade patterns, nor does it deal sufficiently with the micro-level processes of defining interests and strategies in particular in the business sector, despite the extensive coverage of the resulting strategies and behaviour of institutional actors. Improved transparency and accountability of all actors, civil society empowerment, gender equity and knowledge formation are sustainability objectives from Agenda 21 which still lack appropriate implementation strategies.

- For *sociology* the need to integrate the non-symbolic world of physical realities, their impacts on society and vice versa into the analysis is obvious, plus an intensified co-operation with political sciences, psychology and economics;

For all domains of science and engineering, sustainability science requires re-engineering of the fabric of science, its standard methodologies and institutions. However, if successfully implemented, this would significantly increase the value of science for society, enhance its credibility and provide a vast range of new and fascinating research questions. The challenge of sustainability is an opportunity not to be missed.

Joachim Spangenberg is Vice-President of the Sustainable Europe Research Institute (SERI) at Cologne, Germany; he is a member of the Executive Committee of the International Network of Engineers and Scientists for Global Responsibility.

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